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A Computational package for the evaluation of centrifugal turbopumps

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A Computational Package for the Evaluation of Centrifugal Turbopumps

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ABSTRACT

Future space missions will require reusable engine platforms which in some instances will necessitate deep-engine throttling thrust capability. This is accomplished through the off-design operation of the engine fuel pumps. At off-design conditions, there are additional losses associated with centrifugal turbopump operation, leading to inefficiencies and poor pump performance. Future turbopump designs will incorporate various design changes/innovations to address these inefficiencies. Therefore a means to accurately evaluate proposed designs over extended operating ranges is required. The Centrifugal Pump Analysis Code (CPAC) provides this means.

CPAC is a one-dimensional meanline analysis code which provides design and off-design performance predictions based on pump geometry and operating conditions. CPAC is based on the Loss Isolation Code (LSISO) which was written in the early 1970's for NASA Lewis Research Center. The CPAC user interface is a menu driven treed format with an on-line user manual and user help screens. Several enhancements:

* Additional pump elements
* Node based modeling scheme
* Individual or multiple element analysis
* Constant or variable fluid properties
* English or SI unit input/output
* User-friendly interface incorporating
  - various input options
  - online input editting
* Graphical output analysis including test data comparison capability

along with online help and accompaning user's manual make CPAC a versatile tool for turbopump design performance and evaluation.

Based on comparison to experimental test data, the performance prediction of the CPAC code is acceptable from the standpoint that it predicts performance over a wide range of pump speeds and flow rates. It also offers the capability to predict several different pump configurations such as vaneless diffuser pumps, vaned diffuser pumps, volute pumps, single and multistage pumps, including the crossover elements.

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List of Symbols

Symbols	Definition
A	Area
B	Blockage
C	Absolute fluid velocity
C_m	Absolute fluid meridional velocity
C_u	Absolute fluid tangential velocity
D	Diameter, Diffusion factor
D_h	Hydraulic diameter
F	Function of . . .
K	Empirical correction coefficient
L	Length
N	Impeller speed [rpm]
P	Perimeter
Q	Flow rate [Gpm]
Q_{cbft}	Flow rate [ft^3/min]
Re	Reynolds number
S_1	Incidence loss
T_n	Normal thickness
U	Velocity
V_t	Impeller tip speed
W	Relative velocity
WT	Weight flow
w	Passage width
Z	Number of blades
Greek Letters	
η	Efficiency
f	Friction coefficient
g	Gravity
α	Absolute Fluid Flow Angle
β	Blade Angle
β_f	Flow Angle Relative to Blade
ρ	Fluid Density
π	Pi [3.14159....]
σ	Solidity
φ	Flow Coefficient
ϕ	Loss Coefficient
υ	Kinematic Viscosity
Subscripts	
1	Inlet node
2	Outlet node
b	blade
I	inlet
f	fluid

Subscripts (cont.)

tip	Pertaining to a tip location
hub	Pertaining to a hub location
rms	A root mean square value
cbft	Cubic feet units
flow	Pertaining to effective flow area i.e. A_{flow}
i	Pertaining to the ith element
i-1	Pertaining to the previous element
inc	Pertaining to incidence losses
dif	Pertaining to diffusion losses
skf	Pertaining to skin friction losses
scm	Pertaining to scroll momentum losses (Volute)
throat	Pertaining to the throat location
wr	Pertaining to wear ring
des	Pertaining to design point
Act	Pertaining to actual output values
Euler	Pertaining to Euler or ideal values
b1	Inlet blade value
f1	Inlet fluid value
b2	Discharge blade value
f2	Discharge fluid value
1	Inlet Value
2	Discharge value
h	Hydraulic value as in hydraulic diameter D_h

1. INTRODUCTION

1-1.0 Justification of Work

There exists a need for an accurate assessment of proposed centrifugal turbopump designs, especially at off-design conditions, a technology which has become necessary for deep-engine throttling thrust capability. This can be accomplished with an easy to use pump performance prediction code. The code must however be versatile enough to accommodate various pump geometries, including multi-stage pumps and various working fluids. Development of such a code would enable the evaluation of proposed turbopump designs, in addition to functioning as a design tool. This capability could possibly lead to faster pump development as well as lower development costs.

The goal of this project is to develop a user friendly pump performance prediction code based on the Loss Isolation Code, which was developed for NASA in the early 1970's, that is well documented and includes the following features:

* menu-driven user interface
* on-line help
* on-screen editting features
* variable fluid properties capability
* graphical output capability with comparison to test data

A more versatile code is necessary to handle new pump geometries, and good documentation is required so that future experimental and empirical information gained from testing can be incorporated into the program to further improve the codes prediction performance.

1-2.0 Goal of Work

The goal of this work was to expand the Loss Isolation Code (a FORTRAN based code), to a user friendly menu-driven interface that can handle substantially greater geometry flexibility. This was accomplished along with several other enhancements: on-screen input editting, greater output capability including on-screen output, file output, graphical output, and comparison to test data, variable fluid properties, and English or SI unit capability. In addition, the code has been well documented with on-line help and a user's manual which covers all of the theoretical and empirical equations and coefficients.

The performance prediction capabilities of the program are also investigated via several case studies of actual rocket engine centrifugal turbopumps and comparison to test data.

2. ONE-DIMENSIONAL TURBOMACHINERY THEORY

2-1.0 Conservation of Angular Momentum and the Continuity Equation

One dimensional turbomachinery theory assumes that the fluid flow proceeds along a prescribed path of known cross-sections where uniform velocity distributions exist. Therefore, only one point, the location, on this path is necessary to determine the flow conditions. With one dimensional considerations applied to incompressible fluids, the velocity is determined from the cross-section geometry by the continuity equation:

$$Q = VA \tag{2.1}$$

where Q = volume flow rate
V = average velocity
A = cross-sectional area normal to V.

The final task of completely determining the flow conditions is to determine the forces from the impeller and pump casing acting on the fluid as it travels through the pump. The relationship between the fluid velocity and the forces can be determined from the momentum law stated simply as:

$$\Delta t = m\Delta V \tag{2.2}$$

which states that the fluid particle of mass m is given a change of velocity ΔV if the fluid behind the fluid particle exerts a force F on the fluid particle of mass m over a time of Δt. To further examine the momentum of the fluid, the fluid mass flow rate is given as:

$$m' = \rho Q \tag{2.3}$$

The momentum law is then transformed to

$$F\Delta t = m\Delta V$$

$$F = \frac{m}{\Delta t}\Delta V \qquad \text{(2.4a,c)}$$

$$F = m'\Delta V = \rho Q\Delta V = \rho Q(V_2 - V_1)$$

which illustrates that the force F is equivalent to the total flow of momentum into a system (ρQV_1) subtracted from the total flow of momentum leaving a system (ρQV_2). Wislicenus[4] states that "the force action between a stream of fluid and the guiding surfaces in any desired direction is equal to the mass flow rate (ρQ) times the change in the fluid velocity (ΔV) in that direction."

Given the above considerations, it can be shown that the law of constant angular momentum can be used to describe the motion of a frictionless fluid in a space of revolution where no external forces are present, (i.e. no impeller vanes). With the one dimensional assumptions in mind, uniform velocity and pressure distributions, consider a particle that travels from position 1 to position 2 as shown in Figure 2.1.

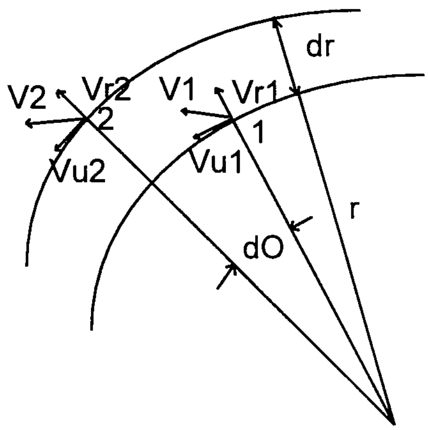

Figure 2.1. Fluid path from position 1 to position 2.

Here the velocity of the particle at the different positions is broken down into the radial and circumferential components. The circumferential velocity V_u is equivalent to the product of the angular velocity and the radius r, and the radial velocity V_r is equivalent to the time rate of change of the particles radial position:

$$r\frac{\partial\theta}{\partial t}=V_u$$
$$\frac{\partial r}{\partial t}=V_r \qquad (2.5, 2.6)$$

as $\delta\theta$ approaches zero ,

$$\lim_{\theta\to 0} V_{r2}=V_{r1}$$
$$\lim_{\theta\to 0}(V_{u2}-V_{u1})=\partial V_u=-V_{r1}\partial\theta \qquad (2.7, 2.8)$$

substituting equations 2.5 and 2.6 into equations 2.7 and 2.8, results in

$$\partial \mathrm{V_u}=-\frac{\partial r}{\partial t}\frac{\mathrm{V_u}\partial t}{r}=-\frac{\partial r}{r}\mathrm{V_u}$$
$$\therefore\frac{\partial \mathrm{V_u}}{\mathrm{V_u}}=-\frac{\partial r}{r} \qquad (2.9a,b)$$

which when integrated becomes

$$\ln V_u = -\ln r + \text{const}$$

or (2.10a,b)

$$V_u r = \text{const.}$$

which states the law of constant angular momentum in a space of revolution. This equation can be rearranged to show that the "circumferential velocity component of the absolute fluid velocity in a space of revolution is inversely proportional to the radial distance from the axis of revolution, provided that no forces are acting in the circumferential direction"[4]. It is necessary to stress that this equation is valid only in the absence of any circumferential force producing elements such as vanes or friction.

The constant angular momentum law is an important consideration in examining the one dimensional fluid flow through a turbomachine, but the limitations preclude its use to examine the impeller/fluid interactions. An additional relationship is necessary to determine the energy transfer to the fluid from the impeller, the conservation of angular momentum. The angular momentum applied to the fluid entering and leaving the impeller is given as:

$$\partial M_1 = -\rho V_{n1} \partial A_1 V_{u1} r_1$$

$$\partial M_2 = \rho V_{n2} \partial A_2 V_{u2} r_2$$

which integrate to: (2.11a-d)

$$M_1 = -\rho \int V_{n1} V_{u1} r_1 \partial A_1$$

$$M_2 = \rho \int V_{n2} V_{u2} r_2 \partial A_2$$

Equations 2.11a-d are the resulting torque exerted by the fluid on the impeller,(1 is entrance, 2 is exit of the impeller). The minus (-) sign on the impeller inlet equation is the convention used for pump processes. The total torque exerted on the impeller by the fluid is

$$M = M_1 + M_2 = -\rho \int V_{n1} V_{u1} r_1 \partial A_1 + \rho \int V_{n2} V_{u2} r_2 \partial A_2 \quad (2.12)$$

This is the Euler relation for the torque exerted on the impeller by the fluid. This relation is simplified by the assumption of constant energy of the flow at the inlet and exit of the impeller. This assumption allows that the products $V_{u1}r_1$ and $V_{u2}r_2$ being constant over the inlet (1) and exit (2) of the impeller, yielding:

$$M = -\rho V_{u1} r_1 \int V_{n1} \partial A_1 + \rho V_{u2} r_2 \int V_{n2} \partial A_2$$

the continuity equation gives

$$Q = \int V_{n1} \partial A_1 = \int V_{n2} \partial A_2 \qquad (2.13\text{-}2.15)$$

therefore

$$M = \rho Q (V_{u2} r_2 - V_{u1} r_1)$$

The sign convention here is discussed. Consider $Vui > 0$ for Vui in the direction of U, (the linear impeller velocity). Therefore for $M > 0$, requires $Vu_1r_1 < Vu_2r_2$, which results in energy transfer from the impeller to the fluid, or pump operation. The case for $M < 0$ requires $Vu_1r_1 > Vu_2r_2$ whereby energy is transferred from the fluid to the impeller, or turbine operation.

The above derivations lead to the relationship between the energy (head) and the momentum of the fluid. The power input from the impeller is equal to the product of the angular velocity (ω) and the torque (M). This power must be equivalent to the power output of the pump which is equal to the product of the flow rate (Q) and pump head (H_i).

$$\omega M = \gamma Q H_i \qquad (2.16)$$

where γ is the specific weight of the fluid, H_i is the total change in energy per unit weight of fluid excluding losses, thus the 'ideal' head. Substituting equation 2.15 into 2.16 with $\rho = \gamma/g$,

$$\omega M = \omega \frac{g}{g} Q(Vu_2 r_2 \quad Vu_1 r_1) = gQH_i$$

which becomes

$$H_i = \frac{Vu_2 U_2 \ - \ Vu_1 U_1}{g} \qquad (2.17\text{-}2.19)$$

where

$$U_i = \omega r_i$$

This equation thus relates the ideal, theoretical, or Euler head of a pump to the circumferential velocities. To further examine this relationship, it is convenient to look at the well known velocity diagrams.

2-2.0 Velocity Triangles

To better understand the basis of the energy transfer, one can examine the average fluid velocity vectors of an ideal fluid in the radial plane of the impeller, normal to the flow direction. These vectors can be broken down into the following components:

V: Absolute fluid velocity

V_r: Relative fluid velocity (to rotor).

U: Linear rotor velocity.

These velocity vectors form a triangle, which represents the one-dimensional state of the fluid at any section of the pump. Typically the velocity triangles are drawn at the impeller inlet and again at the impeller discharge, and are known as the impeller inlet and discharge velocity triangles, (see Figure 2.2). The absolute fluid velocity, (V), can be further decomposed into:

V_m: Meridional (radial) component

Vu: Tangential (circumferential) component.

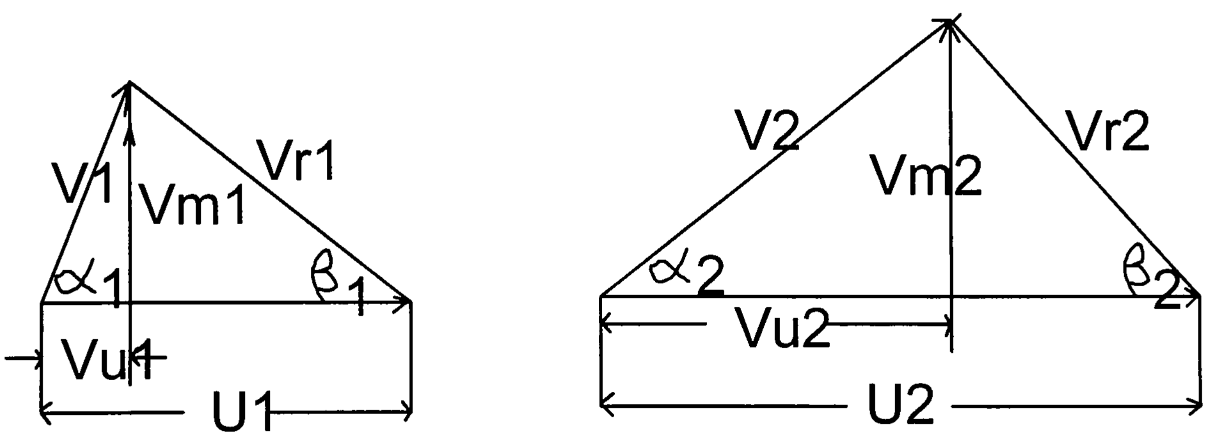

Figure 2.2. Impeller inlet and discharge velocity triangles.

An example of the inlet and exit velocity triangles is shown here for illustration, Figure 2.3. β_1 is the angle between the relative fluid velocity Vr_1 and U_1 + 180 deg. At the discharge of the impeller, β_2 is the angle between the relative fluid velocity Vr_2 and U_2 + 180 deg. These velocity triangles are used to refer to the velocity of the fluid. The angles β_1 and β_2 are usually not identical with the blade angles. The difference between the fluid angle and the blade angle at the blade entrance is known as the angle of incidence. The difference between the fluid angle and the blade angle at the blade exit is known as the deviation angle, and is a result of slip, or imperfect guidance of the fluid by the blades; the blade angle is always larger than the fluid angle, at the blade exit.

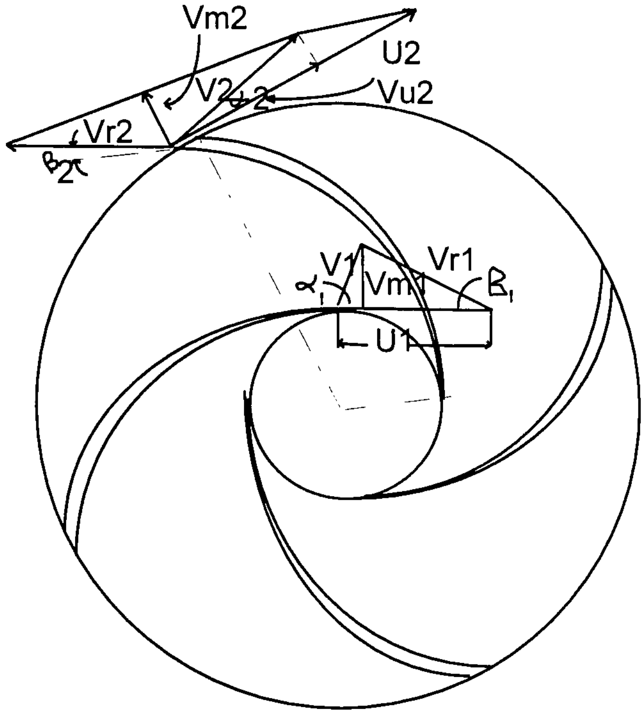

Figure 2.3. Impeller inlet and exit velocity triangles.

In order to determine the meridional velocity component, it is necessary to realize that the meridional velocity always lies in radial planes, resulting in the flow cross-sections being normal to the radial planes, thus normal to the meridional velocity component. Since the cross-sections are normal to the radial planes, they are surfaces of revolution, and normal to the stream surfaces since they are normal to the meridional velocity. This fact results in having to know something about the stream surfaces in order to determine the meridional velocity, which is a 2 or 3 dimensional problem. However, some useful approximations can be obtained from a one-dimensional standpoint.

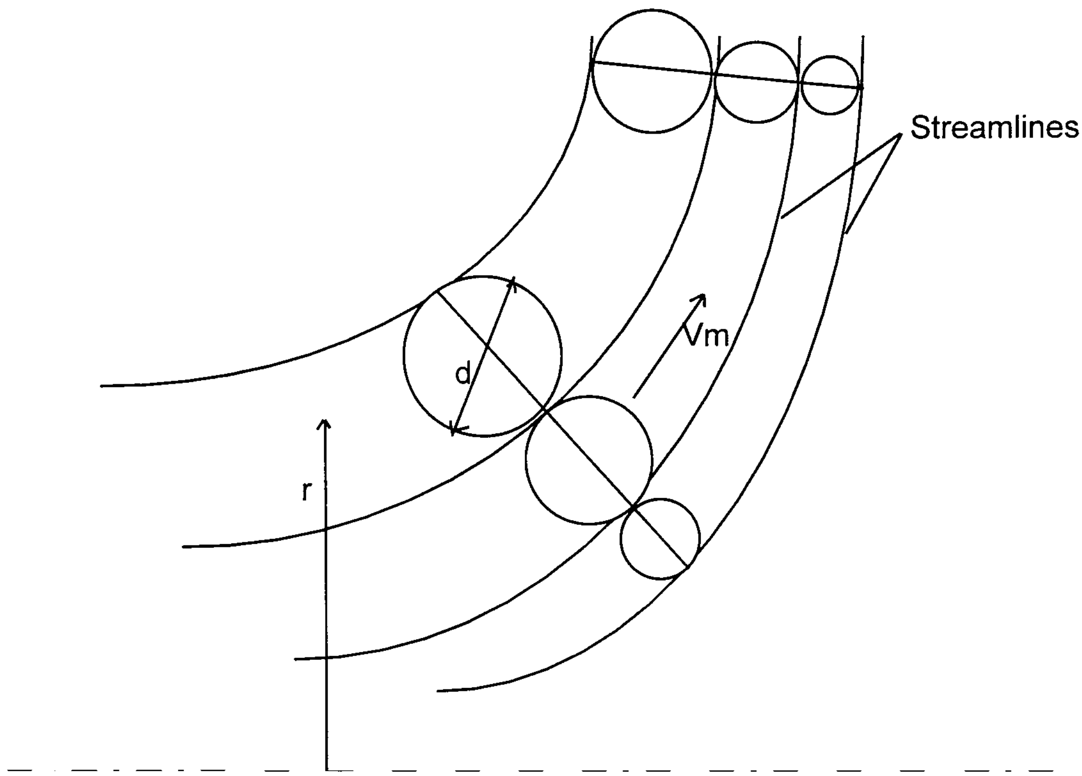

Figure 2.4. Determining the meridional velocity from the continuity equation.

If the revolving space is divided into various cross-sections normal to the prescribed flow direction, (i.e. normal to the wall surfaces), the one dimensional assumption of uniform velocity distributions states that the meridional velocity is uniformly distributed over each cross-section. Furthermore, if each cross-section is divided into the same number of equal parts, (see Figure 2.4), each part being a surface of revolution, each section must satisfy:

$$2\pi r d = \text{const.} \tag{2.20}$$

The meridional velocity then is obtained by applying to each cross-section the condition of continuity.

The objective then of the one-dimensional theory of turbomachinery is to calculate the meridional and tangential velocity components of the fluid absolute velocity V, at the areas of energy input (inducers or impellers), by applying the energy or Euler equation. The velocity components at other pump cross sections are then determined from the continuity and angular momentum conservation laws. In addition, one-dimensional loss mechanism equations (empirical) can be formulated to better approximate the actual average fluid conditions existing in a turbomachine.

The velocity triangles help visualize the fluid velocity vector components, which are determined from the momentum relationships discussed in section 2.1. These relationships constitute the ideal state of energy transfer from the impeller to the fluid in a turbomachine. Unfortunately, the ideal situation is never realized. An attempt to correlate the ideal situation to the factual process must take into account the non-ideal fluid aspects, as well as the non-ideal geometry influences. This results in the following discussion concerning the turbomachine head losses.

2 - 2.3 Head Losses

Useful formulations of pump performance characteristics can be obtained by the systematic accounting of the limitations imposed by the actual pump geometry, and the associated energy losses of the fluid traveling through this geometry. The limitations imposed by the pump geometry stem from the fact that in a turbomachine, perfect guidance of the fluid through the impeller would require an infinite number of impeller vanes, which in reality is impossible; infinite blade number infers a solid disc, which would transfer little or no energy to the fluid. As a result of imperfect guiding, the fluid must expend some energy to 'bend' to follow the impeller blading. This expended energy results in the fact that the head produced by the pump, neglecting losses, will never equal the Euler head expressed in equation 2.18. This expended energy is not considered a loss, in the usual sense of head losses (incidence, friction, etc.), but simply a necessary consequence of a finite number of impeller vanes. The pump output or actual head is further reduced from the Euler head by the various loss mechanisms covered in the following discussions.

Fluid flow in turbomachinery is greatly affected by several loss mechanisms. A knowledge of these mechanisms is paramount to understanding and minimizing the losses resulting in optimized designs. To this end A. J. Stepanoff has classified the loss mechanisms into several groups: leakage, mechanical and hydraulic losses. The mechanical losses include bearing and stuffing box losses, as well as disc friction losses which primarily result in increased power requirements from the pump driver.

Disc Friction:

The major mechanical loss is that which draws input power to overcome the disc friction. The disc friction loss is a result of the spinning rotor front and/or rear shroud imparting energy to the adjacent fluid in a pumping action. This pumping action serves only to expel the fluid to the periphery of the disc where it eventually leaks back to the disk hub where it is pumped out again. This loss has been shown to follow an equation of the form:

$$\text{disc friction loss} = Kn^3D^5 \qquad (2.21)$$

K is an empirical coefficient determined from experimentation, n is the rotor speed in rpm, and D is the impeller shroud diameter. The additional mechanical losses of bearings and stuffing boxes are well known and amount to a very small percentage of the overall pump losses (typically <1-2%).

Leakage Losses:

The leakage losses are primarily concerned with leakage from the impeller exit back to the impeller inlet. These losses are minimized by the use of labyrinth seals and or wear rings. These losses typically vary as a function of the pressure drop across the leakage path, the common form of the leakage loss equation is shown in equation 2.22.

$$Q_L = CA\sqrt{2g\Delta H_L} \tag{2.22}$$

where C = Discharge coefficient

A = Clearance area

ΔH_L = Head drop

As a percentage of the power input, the power loss resulting from leakage effects is reduced at increased specific speeds, and typically less than 2% of the input power at specific speeds greater than 1500, see chapter 3 for a defmition of the specific speed.

Hydraulic Losses

Skin Friction Loss:

The hydraulic losses are the most important losses that should be accounted for in any type of pump analysis. Essentially the hydraulic losses can be categorized into two classifications, friction losses and turbulence losses. The Friction loss results from the skin-friction affect of the internal fluid flow through the pump. The form of the skin friction loss is dependent on the friction factor which is determined from the relative roughness of the passage walls, and the flow Reynolds number.

$$\text{Friction Loss} = f\frac{L}{D_h}\frac{V^2}{U^2} \tag{2.23}$$

Where L is the flow path length across the surface, and is dependent on the fluid flow angle. To get an idea of how the friction loss coefficient will vary with flow rate, it is

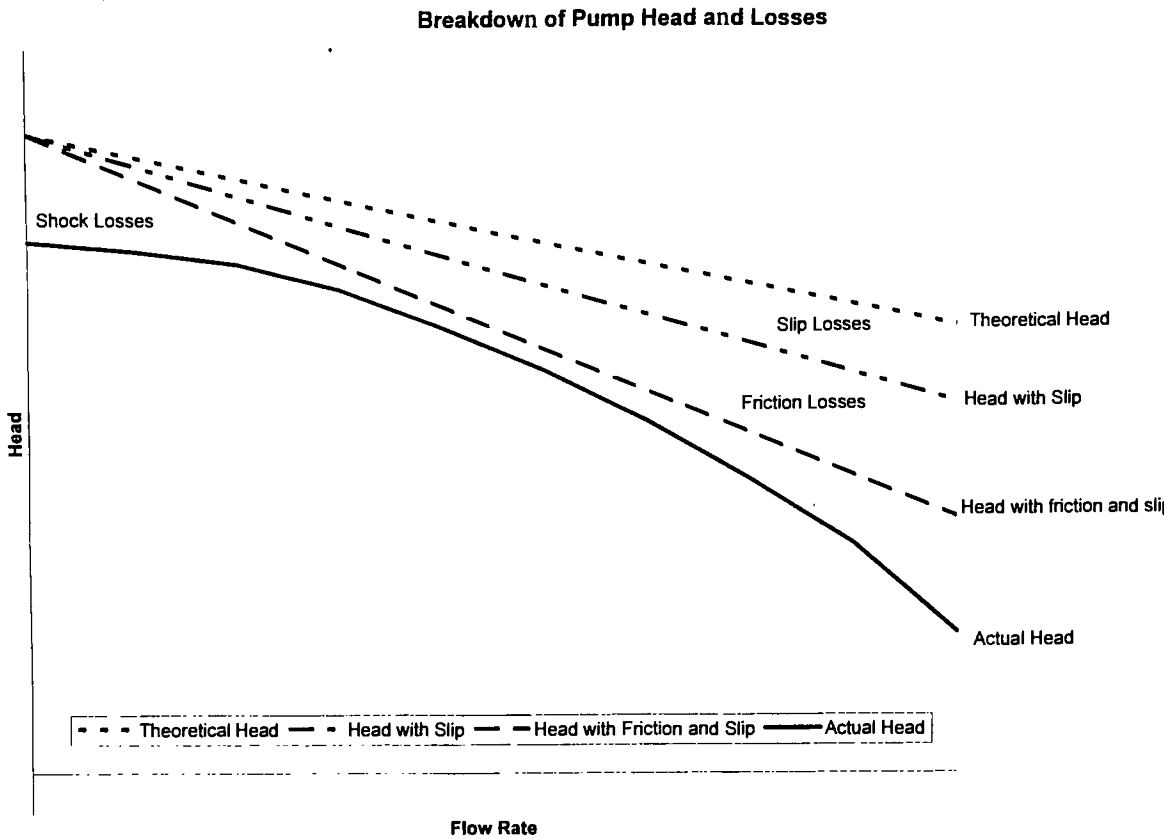

Figure 2.5. Various pump loss mechanisms.

necessary to note that as the flow rate increases so does the fluid flow angle. The friction factor can be estimated from the moody diagram based on the Reynolds number and relative roughness values. In most pumping situations, the Reynolds number is high, which is characteristic of fully turbulent flow conditions resulting in the fact that the friction factor becomes independent of the Reynolds number, and is solely dependent on the relative roughness. The friction factor thus determined from the roughness, the skin friction loss is then dependent on the fluid velocity and the path length. Therefore shorter lengths result in lower friction losses.

Incidence Loss:

The turbulence losses consist of the incidence (shock) and diffusion losses. Any time that the fluid impinges on a 'blunt' edge, separation is likely resulting in flow losses. This shows the importance of proper blade angles, and how losses of this type are an important issue when concerned with off-design performance, where the fluid velocity vectors differ greatly from the blade angles. The incidence loss has been expressed as

$$\text{Shock Loss} = K\,(Q - Q_{\text{shockless}})^2 \qquad (2.24)$$

where K is an empirical coefficient again determined from experimentation. This equation obviously shows that at some flow rate $Q_{\text{shockless}}$ the optimum conditions exist which minimize the incidence or shock loss, ideally there would be no incidence loss. It is many times assumed that the $Q_{\text{shockless}}$ flow rate is the design flow rate.

Diffusion Loss:

The diffusion loss is associated with flow separation that occurs when the flow is expanded too rapidly. The form of the diffusion loss is similar to the friction loss equation, where instead of a friction factor a diffusion factor is determined empirically.

$$\text{Diffusion Loss} = K(\text{diffusion factor})^{N} \qquad (2.25)$$

where N is typically 2 or 3 depending on the type of pump element under consideration.

The one-dimensional theory of loss mechanisms is mainly concerned with the hydraulic losses, which effect the pump capacity curve as shown in Figure 2.5. The CPAC code attempts to calculate the hydraulic and leakage losses, as well as the mechanical disk friction loss. The equations used in the code are presented in the appropriate sections and appendix B.

The preceding sections discuss the one dimensional theory of turbomachines which relate the operating conditions to the average fluid velocities resulting from the fluid traveling a prescribed path through the machine. It was shown that this path through the machine with the appropriate assumptions (namely uniform velocity distributions), results in the flow being uniform along circles normal and concentric to the axis of rotation, with the exception of where the circles are intercepted by the impeller vanes. The fluid path not only revolves around the axis, (resulting in the circumferential velocity component V_u), but is also flowing through the machine, giving a meridional velocity component V_m which is normal to the circumferential direction. Therefore, the determination of a pump's performance characteristics consist of the following steps:

1). Determining the circumferential velocity component from the torque and head of the impeller, using the Euler equation.

2). Determining the meridional velocity component from the pumps through-flow capacity using the continuity equation, and

3). Determining the actual pump output head and capacity by accounting for the head and capacity losses using the discussed empirical equations.

---

3. Centrifugal Turbopumps

3-1.0 Centrifugal Turbopump Applications

Centrifugal turbopumps derive their name from the fact that they are driven by high speed turbines of rocket engines. The requirements of these rocket engines determine the design parameters of the pump. Centrifugal turbopumps may be single or multistage designs as shown in Figures 3.1 and 3.2. These figures show that these types of pumps consist of many of the same elements found in other types of pumps, i.e. impellers, diffusers, and volutes. The remainder of this section discusses some of the important pump parameters that must be considered in centrifugal turbopump design. The required pump flow rate and pump head rise are the basic parameters imposed on the turbopump system from the rocket engine design thrust and combustion chamber parameters. In order for the rocket engine to achieve design thrust capability, the turbopump system must deliver the appropriate propellant flow rate at a discharge pressure which is sufficient to overcome the hydraulic resistance (line losses), the fuel injector pressure drop, and combustion chamber pressure. Another important parameter is known as the Net Positive Suction Head.

The Net Positive Suction Head, (NPSH), is the difference between the fluid head due to total fluid pressure and the head due to the fluid vapor pressure, at the pump inlet. If the NPSH is lower than a certain value, cavitation will occur at the pump impeller inlet which will lower the pump head rise below the design value. A typical critical value of the NPSH is where the head rise is 2% lower than the non-cavitating head rise value. This cavitation phenomena although prevalent at the pump impeller inlet, where the lowest absolute pressure is often encountered, can occur anywhere in the pump where the static pressure becomes less than the fluid vapor pressure. Excessive cavitation has been known to result in erratic combustion leading to excessive vibrations and even explosions.

As mentioned in the above sections, future applications will require engine throttling, which result in pump operation at off-design conditions. At off-design conditions, the turbopump system encounters the most severe operating conditions. The limits imposed on throttleability, are a result of the pump becoming unstable. Centrifugal turbopumps have approximately twice the throttleability capability as axial pumps, and increased design speed improves the centrifugal turbopump throttleability. To meet these new requirements, single and multistage centrifugal pumps will be continually used in turbopump systems. For this reason, the importance of improved design methods as well as improved performance prediction capability, can not be overstated.[11]

Engine throttling, requires pump operation at off-design conditions, meaning at flow rates other than the design flow rate, as well as operating speeds at other than the design speed. Dimensional analysis and similitude has historically been applied to predict pump performance at these off-design operating points.

3-2.0 Dimensional Analysis and Similarity Relations for Turbomachinery

In the interest of more efficient turbomachine development it is often necessary to perform experimentation on scaled models of turbomachines to predict the performance of larger/smaller geometrically similar prototype machines. This requires dynamic similarity which requires duplicating all but one of the dimensionless groups. Historically the following variables have been used in dimensional analysis of turbomachines:

D: Diameter, representing machine size.
Q: Machine Capacity - Volume Flow.
H: Machine Energy - Head Change.
N: Machine speed.
ν: Fluid kinematic viscosity.
g: Gravitational constant.

These variables involve 2 basic dimensions, length L and time T, as shown in Table 3.1.

Table 3.1 Variable Dimensions

Variable	D	Q	H	N	ν	g
Dimensions	[L]	[L^3/T]	[L]	[1/T]	[L^2\T]	[L\T^2]

Buckingham's π theorem suggests that this will result in 4 dimensionless groups which will characterize the flow of fluid through the turbomachine. Experience has shown that the following dimensionless groups form functional relationships which identify important parameters of the flow:

$$\beta\left(\frac{Q}{ND^3}, \frac{\Delta H}{D}, \frac{g}{N^2 D}, \frac{ND^2}{\nu}\right) = 0 \qquad \textbf{3.1}$$

The last dimensionless group, ND^2/ν when examined more closely can be interpreted as the Reynolds number, (since ND is proportional to the impeller tip speed, U_t). For large rotational Reynolds numbers, $U_t D/\nu$ the viscous/frictional effects are negligible on the turbomachine performance. Thus equation 1 can be simplified to

$$\Gamma\left(\frac{Q}{ND^3}, \frac{\Delta H}{D}; \frac{g}{N^2 D}\right) = 0 \qquad \textbf{3.2}$$

In these cases one can solve for ΔH/D resulting in

$$\frac{\Delta H}{D} = \Gamma_1\left(\frac{Q}{ND^3}, \frac{g}{N^2 D}\right) \qquad 3.3$$

Therefore, similitude requires duplicating the dimensionless groups Q/ND^3 and g/N^2D. Further analysis shows that the first dimensionless group Q/ND^3 can be broken down in the following way:

$$\frac{Q}{ND^3} = \frac{\frac{Q}{D^2}}{ND} = \frac{K * (\text{exit velocity})}{J * (\text{tip velocity})} \qquad 3.4$$

thus Q/ND^3 is related to the ratio of the machine fluid exit velocity to the machine impeller tip speed. This is typically referred to as the flow coefficient. Kinematic similarity of the streamlines between two flows (dynamic similarity) requires that the flow coefficient be matched for the two flow fields.
Experiment has shown that the last dimensionless group in equation 3.3, g/N^2D occurs to the power -1 in the Γ_1 relation thus equation 3.3 can be rewritten as

$$\frac{\Delta H}{D} = \frac{N^2 D}{g} \Gamma_2\left(\frac{Q}{ND^3}\right) \qquad 3.5$$

which simplifies to

$$\frac{g \Delta H}{N^2 D^2} = \Gamma_2\left(\frac{Q}{ND^3}\right) \qquad 3.6$$

The dimensionless group $g\Delta H/N^2D^2$ is commonly known as the head coefficient, which is proportional to the ratio of the mechanical energy per unit mass to the impeller tip speed squared. This analysis has reduced the similitude requirements to two dimensionless groups. Thus if the flow coefficient is matched between two geometrically similar machines of different size, the flows must have the same head coefficient assuming one has dynamic similarity between the flows. Therefore the head and flow coefficients are very useful in comparing families of geometrically similar machines. There is a third dimensionless group which can be formed form the head and flow coefficients known as the specific speed which is useful for comparing different families of turbomachines. The specific speed is defined as

$$N_s = \frac{\left(\frac{Q}{ND^3}\right)^{\frac{1}{2}}}{\left(\frac{g \Delta H}{N^2 D^2}\right)^{\frac{3}{4}}} = \frac{N\sqrt{Q}}{(g \Delta H)^{\frac{3}{4}}} \qquad 3.7$$

The powers of the numerator and denominator were chosen such as to eliminate the diameter variable D. The specific speed is useful for determining which type of turbomachine to use for a particular application. If for example the service conditions for an application were known, speed, head and flow rate, the specific speed can be calculated. Based on the value of the specific speed, the type of turbomachine can be selected, since it is well known that Radial flow machines exhibit the highest efficiencies for low specific speed values, followed by mixed flow machines for higher specific speed values, and axial flow machines for high specific speed values.[13]

3-3.0 Centrifugal Pump Efficiency Relations

The actual useful head of a centrifugal turbopump is always less than the head which theoretically should be produced. This phenomena is a result of the various head losses discussed in section 2-2.3. The ratio of the actual head to the theoretical head is known as the hydraulic efficiency of the pump. In addition to the hydraulic efficiency, there are several other efficiencies associated with pumps. These efficiencies are now summarized.

Hydraulic Efficiency:

$$\eta_{\mathrm{Hyd}} = \frac{\text{Actual Head}}{\text{Theoretical Head}} = \frac{H_{\mathrm{act}}}{H_{\mathrm{th}}} \qquad \textbf{3.8}$$

The hydraulic efficiency is the ratio of the actual head to the theoretical or virtual head produced by the pump. It is necessary to note that the theoretical head is the head produced by a finite number of blades. The losses contributing to the lower actual head are mainly the frictional and turbulence losses.

Volumetric Efficiency:

$$\eta_{\mathrm{vol}} = \frac{\text{weight flow delivered}}{\text{weight flow delivered} + \text{leakage flow}} \qquad \textbf{3.9}$$

The volumetric efficiency is simply a measurement of leakage flow through the machine, The higher the volumetric efficiency, the lower the leakage flow.

Mechanical Efficiency:

$$\eta_{\mathrm{mech}} = \frac{\text{power available at rotor}}{\text{power delivered to pump shaft}} \qquad \textbf{3.10}$$

The mechanical efficiency is the ratio of the power transmitted to the fluid from the impeller, to the power supplied to the pump shaft.

Overall Efficiency:

$$\eta_{\mathrm{over}} = \frac{\text{fluid horsepower output}}{\text{brake horsepower input}} \qquad \textbf{3.11}$$

The overall efficiency of the pump is the ratio of the fluid horsepower output to the brake horsepower input. The brake horsepower represents all of the power supplied to the pump unit. This power is used to increase the fluid horsepower, overcome the frictional and turbulent losses. the leakage losses. disc friction losses. and the various mechanical losses. Therefore the overall efficiency can be represented as:

$$\eta_{over} = \eta_{hyd}\eta_{vol}\eta_{mech} \tag{3.12}$$

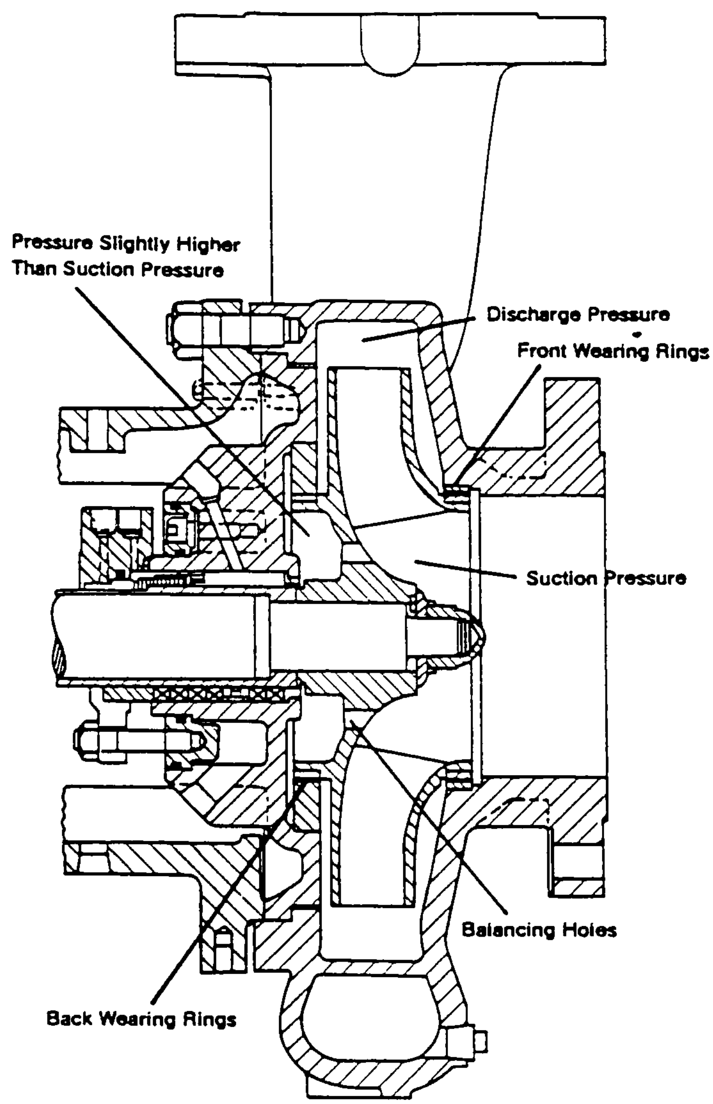

Figure 3.1. Single stage centrifugal pump.

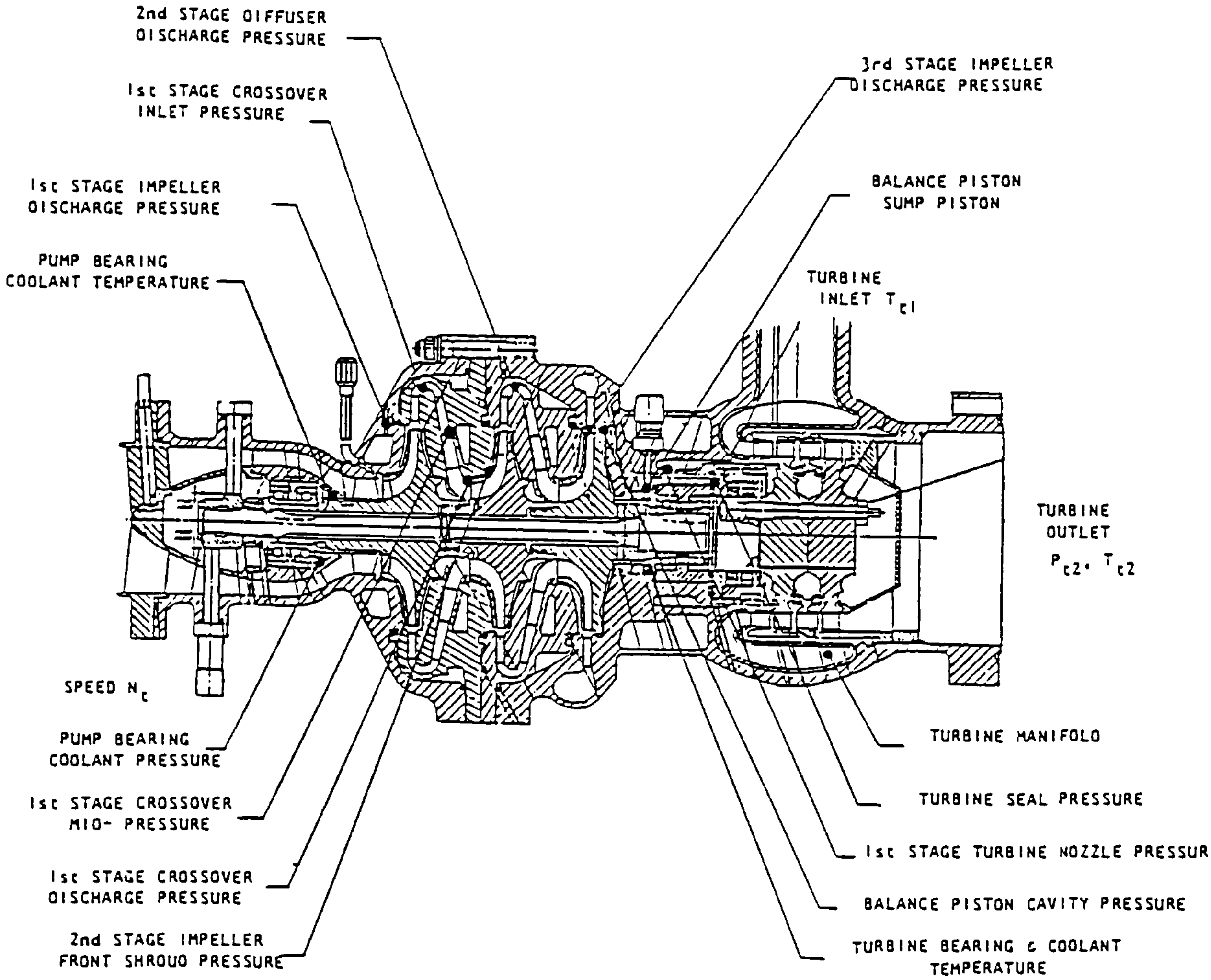

Figure 3.2. Multistage centrifugal turbopump.

4. CPAC Centrifugal Pump Analysis Code

4-1.0 Introduction to CPAC

The CPAC code is a one-dimensional mean-line performance prediction code for centrifugal turbopumps. The code predicts performance at design and off-design conditions. A thermodynamic properties code has been integrated to the code which adds variable fluid property capability for water, liquid hydrogen, liquid oxygen, and nitrogen. The CPAC code is an outgrowth of the Loss Isolation Program developed for NASA, in the early 1970's.

The CPAC code is written in FORTRAN-77, and is over 13,500 lines in length, and runs in a DEC Vax VMS environment. In addition to the source code, links are made to the thermodynamic properties calculation code, GasPlus and to graphics packages for graphical output capability. The following list shows some of the features that have been added to the original program:

1. Menu-Driven Format
2. Available On-line Help
3. English or SI Units for Input and Output
4. Constant or Variable Fluid Properties
5. Element and Node Based Pump Modeling
6. Addition of Crossover and Downcomer Type Elements
7. Single or Multiple Element Calculations
8. Single or Multistage Pump Modeling Capability
9. Tabular or Graphical Output Analysis
10. Ability to Graphically Overlay Test Data on Predicted Performance Map.

The forward and reversing menu structure is very easily traversed and the on-screen HELP feature explains the required steps for operating the current menu screen.

The CPAC code predicts centrifugal pump performance based on the modeled pump geometry, flow rates and operating conditions using empirical equations and experimental coefficients. The code has been well documented with the hope that as new experimental data, and advancing technology permit, the coefficients and empirical equations could be modified to improve its performance prediction capability.

4-1.1 Running CPAC

There are three steps to running the program, these steps are shown in Figure 4.1. The first step is to specify the program input data, which contains the pump configuration, geometry, operating conditions and the mapping parameters. The input can be read in from a stored file, or, interactively input from the keyboard. Once the data has been entered, the code is now ready for a calculation run. Once the calculations are completed, the program output can be examined.

INPUT → RUN → OUTPUT

Figure 4.1. Simplified CPAC program sequence.

There are many means of viewing the program output: on-screen, printed tabular output, and graphical output. A unique feature of the graphical output is the ability to overlay actual test data performance map points onto the predicted performance curves. Once the program output has been analyzed, one could modify the input data and rerun the program, which lends itself to design optimization.

4-1.2 Menu Structure and Features

The CPAC code is structured in a menu-driven, treed-format shown schematically is Figure 4.2, with on-line help available.

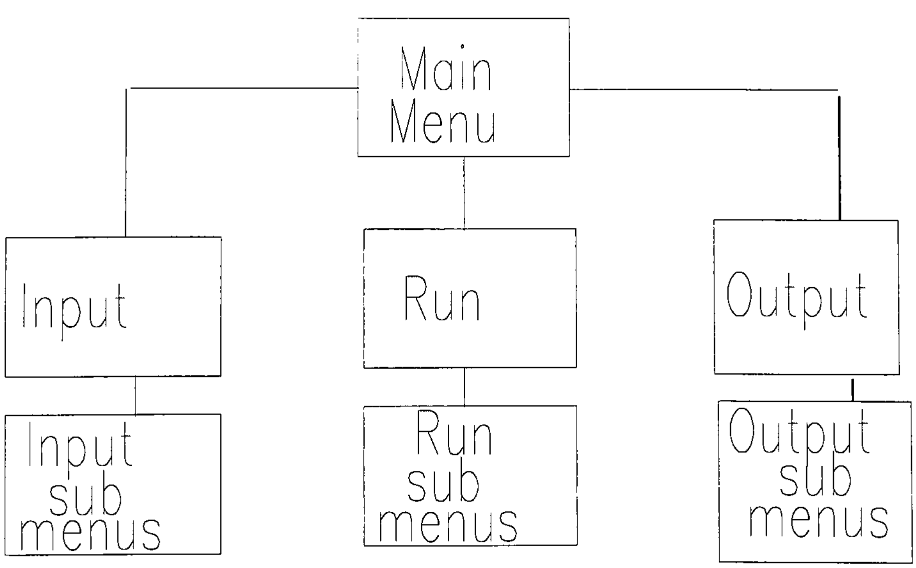

Figure 4.2. Schematic of CPAC Program menu structure.

A typical screen is shown in Figure 4.3. The top of the screen shows the program name, and the menu level. The center of the screen is where the user chooses the appropriate options, while the bottom of the screen gives a list of command keys which are available. These command keys vary with the menu. Only command keys which are appropriate for that menu are shown as available. The most common command keys are shown in Table 4.1 marked with an asterisk (*).

```
CPAC                                                  MENU 1.2

                 INPUT/EDIT FROM KEYBOARD
                   MODEL CONFIGURATION
                   SYSTEM PARAMETERS



        |H-HELP|E-END|M-MAIN MENU|P-PREVIOUS MENU|
```

Figure 4.3. Input options.

Table 4.1. Command keys (* = most common keys).

H-Help*	**E**-End*	**M**-Main Menu*
P-Previous Screen	**D**-Delete	**I**-Insert
RTN-Next	**T**-Print	**L**-Return to List

Command Keys

There is on-line help for virtually every menu screen that may come up. Listed here are some of the more common command keys with an explanation of their use.

Command

H-Help (selected by hitting the **H** key), calls up the help information relative to the current menu.

E-End (selected by hitting the **E** key) stops the program. When this command is entered, a warning is issued that the program is about to end, and the code asks for confirmation of this command.

Command

M-Main (selected by hitting the **M** key) returns the program to the main menu.

P-Previous screen (selected by hitting the **P** key) returns the program to the previous menu screen.

D-Delete (selected by hitting the **D** key) deletes the current selection.

I-Insert (selected by hitting the **I** key) inserts the appropriate item.

RTN-Next (selected by hitting the **Return** key) allows one to move on to the next logical input or output screen without stepping back to a menu selection screen.

T-Print (selected by hitting the **T** key) prints the screen to a local printer available when a local printer is available.

L-Return to List (selected by hitting the **L** key) command is available when one is viewing the program output in tabular format on the screen. It functions to bring the program immediately back to the output parameter selection screen, in order to select a different parameter to view.

As shown in the Figure 4.1, one needs to input the pump model to the program, choose which run mode to select, run the code, and view the output. These steps are explained in detail in the following sections. Again, on-line help is always available, by choosing the **H-Help** command key. Figure 4.4 simply illustrates the process for using the **CPAC** code to evaluate a pump's predictive performance.

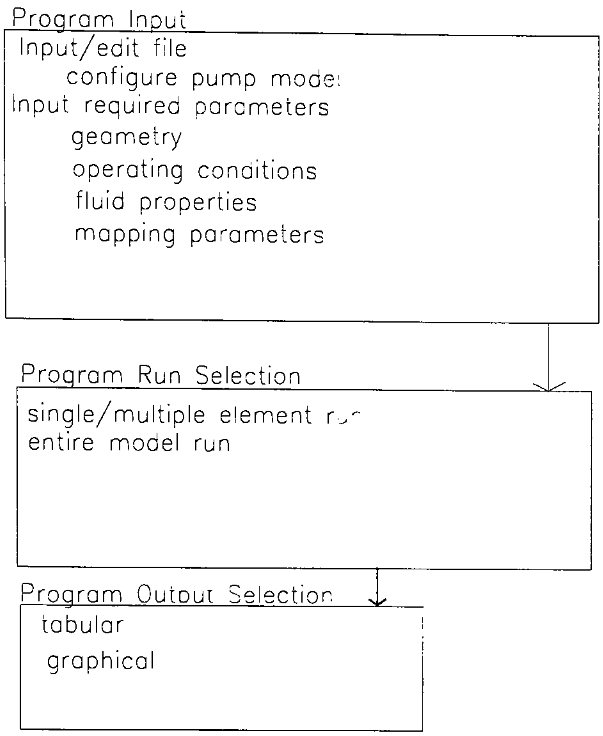

Figure 4.4. Steps to take to perform CPAC prediction analysis.

4-2.0 Input Options

The first step in predicting a pump's performance is to model the pump geometry. This section discusses the program input options available to the user. Section 4-3.3 introduces the concept of pump modeling by setting up a series of pump elements connected to each other through nodes.

CPAC MENU 1

INPUT OPTIONS
INPUT FROM A FILE
EDIT/DISPLAY/INPUT FROM KEYBOARD
SAVE INPUT TO A FILE

CHANGE UNITS (CURRENT:ENGLISH)

| H-Help | E-End | M-Main menu | P-Previous screen |

Figure 4.5. Input options menu.

There are 4 options available on the input options menu screen in addition to the command key options. These options are shown in Figure 4.5.

INPUT FROM A FILE:	Allows one to enter a file from an on-screen file list, to manipulate or run through the CPAC code.
EDIT/FROM KEYBOARD:	Allows one to edit or display the file just retrieved from the first option, or, to enter a new pump model input file from the keyboard.
SAVE INPUT TO A FILE:	Allows one to save the input file currently in memory to an available input file to be recalled at another time.
CHANGE UNITS:	Allows one to switch between English or SI units for the input file parameters. The current units are shown in parenthesis.

Choosing option 1 calls up a screen which displays all the current input files available to read in. These files are each assigned a number which when selected automatically is read in to the computer memory. The files can also be deleted by choosing the **D-delete** option and then choosing the appropriate file number.

The **D-delete** option does require some further explanation. When the **D-delete** option is invoked, the program prompts for a file number which to delete. This is an option that demands extreme caution, since any file which is deleted is no longer available as an input file. The file name only is deleted from the list of available input files. The actual file still exists in the same directory, and may be recalled by choosing file number 30 and entering the full path and name of the file.

Choosing option 2 allows input from the keyboard. This option is useful for editing the current input file, or if necessary, to input a totally new input file. When option 2 is chosen, the next menu to appear is menu number 1.2. This menu offers the options to configure the pump model, or to enter the pump element parameters. The pump element parameters include element geometry, operating conditions, fluid/type parameters, and mapping parameters.

The third option is **SAVE INPUT TO A FILE**, which when selected results in a file listing screen. This allows one to save the input file currently in memory to an available input file to be recalled at a later date. The final option, **CHANGE UNITS (CURRENT:ENGLISH)**, allows one to switch between English and SI units for the input file parameters.

The command keys available on the input option menu screen are the standard 4 command keys, **H-Help, E-End, M-Main menu, P-Previous screen**. However, the on-screen file listing contains the additional command key **D-Delete**, which allows one to purge files from the listing.

Once the process of selecting an input method has been completed, the next step is to provide the input to the code. This step may require starting to input a pump model from scratch, or modifying an existing model. The actual processes are described in the modeling section, section 4-3.3.

4-3.0 Modeling Technique

The technique for modeling a centrifugal pump in CPAC is relatively straight forward. The CPAC code calculates the theoretical head input from the pump impellers, then analyzes the head and capacity losses associated with the modeled pump. These losses are dependent on the pump geometry and operating conditions. Therefore to correctly predict the pump performance, the pump must be correctly modeled. This is accomplished by configuring the model with the appropriate pump elements, and operating conditions.

A pump is modeled as a series of pump elements connected to each other at nodes. A list of all the currently available element types is shown in Table 4.2. These elements figuratively represent the major geometry sections of a centrifugal turbopump. As discussed in section 2. Under the Leakage element there are several different leakage configurations, such as front or rear shroud leakage, front balance ribs, etc., these are shown in table 4.3.

Table 4.2. Element types.

Inducer	Turning channel
Stator	Downcomer
Impeller	Return Channel
Vaneless Diffuser	Volute (single or double discharge)
Vaned Diffuser	Exit Diffuser (single or double discharge)

Table 4.3. Leakage Element Types

Front face of Impeller	Rear face of Impeller
Front Shroud	Rear Shroud
No Front Shroud	No Rear Shroud
Front Wear Ring	Rear Wear Ring
Front Balance Ribs	Rear Balance Ribs

In order to model a pump correctly, one should break up the actual pump geometry into the appropriate pump elements listed in Table 4.2. When the pump elements have been selected they must be connected in the proper order through the element node numbers which correctly traces the fluid path through the pump. This process is accomplished very easily through an interactive process. Once the pump geometry has been correctly modeled, the required program input parameters must be entered into the program input file, this is also done interactively. An example of a pump modeling session is discussed in section 4-3.4. When these steps have been completed, the pump model is ready to by run through the CPAC code which will predict the pump performance.

4-4.0 Model Example: XLR-134 Turbopump.

This section discusses a typical CPAC modeling session. Figure 4.6 shows a schematic which graphically shows the pump elements, nodes, and the fluid flow path.

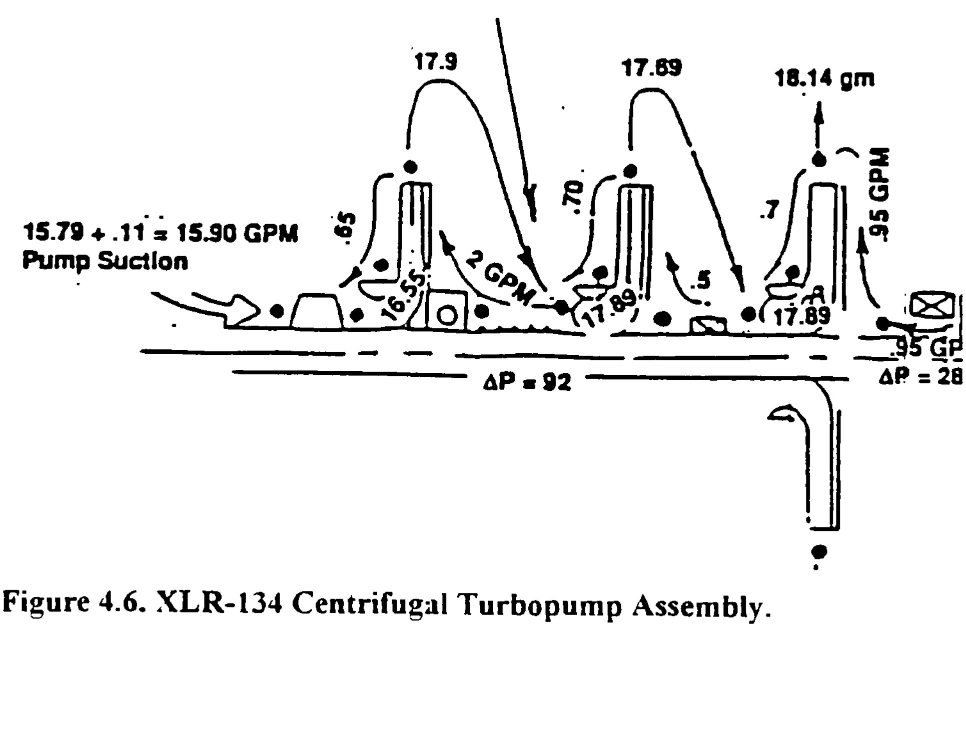

Figure 4.6. XLR-134 Centrifugal Turbopump Assembly.

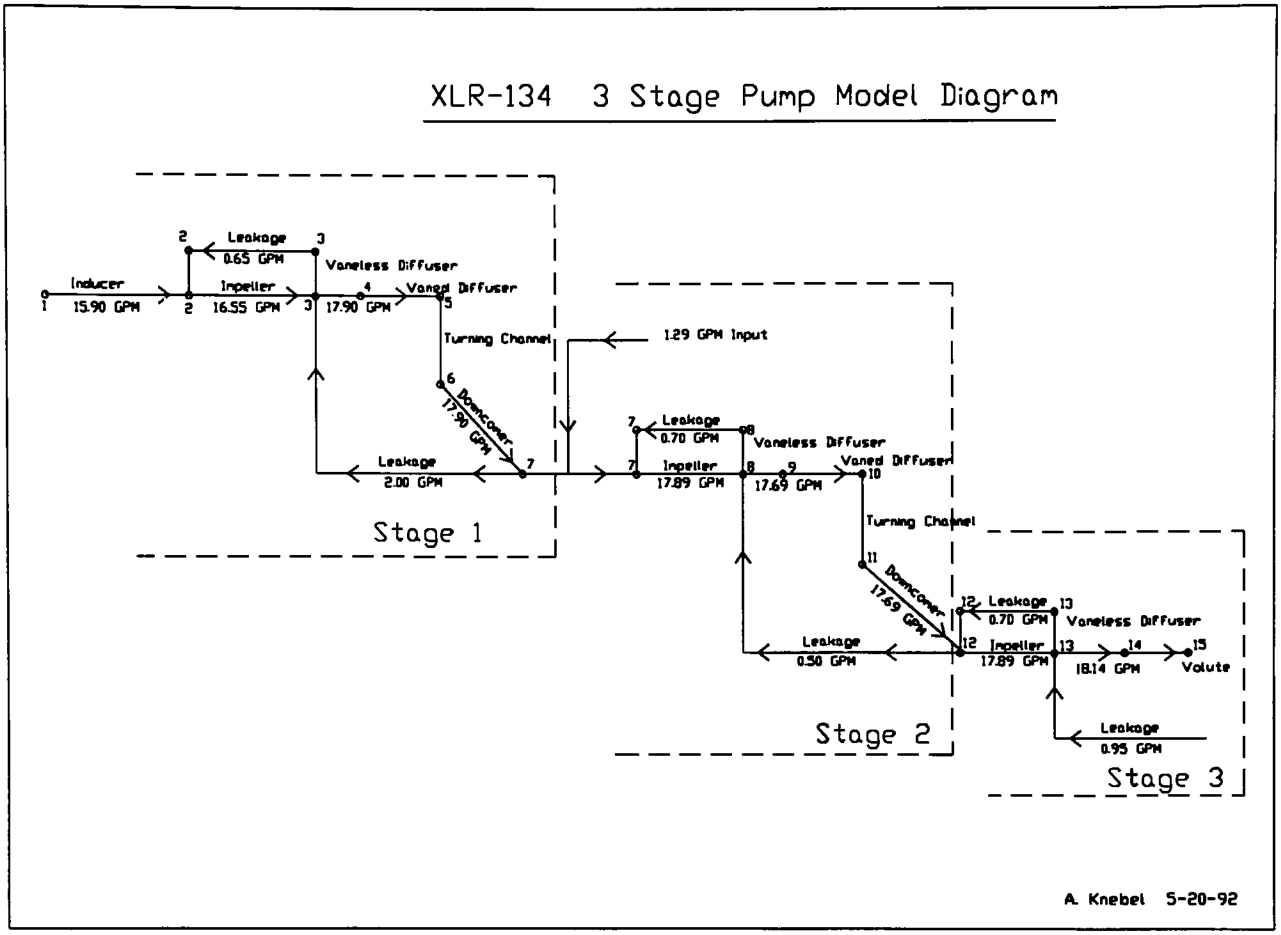

Figure 4.7. Schematic of a CPAC model (XLR-134).

This model schematic of the XLR-134 Centrifugal Turbopump depicts spool 1 of the actual turbopump consisting of 3 stages separated by crossover assemblies. Further investigation into the reference material[10] resulted in the first stage consisting of an inducer followed by an impeller with associated leakage, leading to a vaneless diffusing section and a vaned diffuser. The cross over assembly is modeled as a turning channel followed by a downcomer element which in turn leads to the second stage impeller. The second stage impeller is followed by a vaneless diffusing section leading again to a vaned diffuser followed by the second stage crossover assembly. The third stage impeller leads to a vaneless diffuser followed by a single discharge volute element. This configuration is shown in Figure 4.7; such a schematic layout is suggested as it aids in the CPAC modeling process. Once the elements and node order are determined for the model, the model is constructed interactively through the menu-driven interface in CPAC. This is an iterative process where the elements are selected from pop-up menus and the node numbering determines the element order as well as the fluid paths. This model configuration as it appears in CPAC is shown in Figure 4.8.

CPAC MODEL 3 STAGE XLR-134

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET NODE	DISC. NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	VANED DIFFUSER	4	5
5	TURNING CHANNEL	5	6
6	DOWNCOMER	6	7
7	LEAKAGE w/ FS FWR	3	2
8	IMPELLER	7	8
9	VANLESS DIFFUSER	8	9
10	VANED DIFFUSER	9	10
11	TURNING CHANNEL	10	11
12	DOWNCOMER	11	12
13	LEAKAGE w/ FS FWR	8	7
14	IMPELLER	12	13
15	VANLESS DIFFUSER	13	14
16	1-DISC. VOLUTE	14	15
17	LEAKAGE w/ FS FWR	13	12

Figure 4.8. XLR-134 Model configuration, CPAC screen.

Note that each impeller element is modeled along with its associated leakage element. This assembly of elements is connected via inlet and discharge nodes which constitute the flow paths through the pump. It is also necessary to note that in this particular model, additional leakage paths are modeled which are shown in Figure 4.7, without any origin nodes. These elements are modeled as bypass flow rates, and are necessary to depict flow entering or leaving the spool 1 model to or from elsewhere in the actual turbopump (see turbopump assembly Figure 4.6).

Once the model is constructed the next step is to enter the required geometric parameters for each element. This is accomplished by selecting the desired element and entering the requested geometric parameters into the menu screen.

Input Parameters

Geometry

Each element has several geometric parameters which must be input in order for acceptable prediction performance. Although most of the elements require similar input items such as hub and shroud inlet and exit diameters, some of the more unique elements such as the volute or downcomer require different parameters. The CPAC code determines the appropriate items for the selected element and displays these items on the menu input screen. Figure 4.9 shows the input screen for an impeller element for the XLR-134 pump model.

```
CPAC                                          MENU 1.2.2.1
             GEOMETRY (ELEMENT # 2:IMPELLER)

           INLET TIP DIAMETER [in]            0.643
           INLET HUB DIAMETER [in]            0.399
           INLET PASSAGE WIDTH [in]           0.122
           INLET BLADE ANGLE [deg]            20.3
           NUMBER OF INLET BLADES             8
           INLET NORMAL THICKNESS [in]        0.01
           INLET BLOCKAGE                     0.95
           DISCH. TIP DIAMETER [in]           1.873
           DISCH. HUB DIAMETER [in]           1.873
           DISCH. PASSAGE WIDTH [in]          0.064
           DISCH. BLADE ANGLE [deg]           40
           NUMBER OF DISCH. BLADES            8
           DISCH. NORMAL THICKNESS [in]       0.01
           DISCH. BLOCKAGE                    0.9
           BLADE LENGTH [in]                  0.25
           SURFACE ROUGHNESS [in]             0.00001

| H-Help | E-End | M-Main menu | P-Previous screen | N-Next element |
```

Figure 4.9. Impeller geometry input screen.

The next logical step, once all of the elements' geometry have been entered, is to input the operating conditions with which to analyze the pump's performance.

Operating Conditions

Each element has operating conditions which are prompted for by the program, when an element is selected for operating conditions input. Figure 4.10 shows the operating conditions for an impeller element for the XLR-134 pump model. Other elements such as inducers and diffusers, do not require as an extensive list of operating conditions as shown in Figure 4.11. Similar to this operation is the input of the fluid properties for each element.

CPAC MENU 1.2.2.2

OPERATING CONDITIONS (ELEMENT #2:IMPELLER)

HEAD COEF AT MAX. EFFICIENCY	0.45
IMP. DISC. FLOW COEF AT MAX. EFF.	0.05
IMPELLER CLEARANCE TORQUE COEF	0.01
IMPELLER BLADE LOADING COEF(AA)	-6328.56
IMPELLER BLADE LOADING COEF (BB)	3143.02
IMPELLER BLADE LOADING COEF (CC)	-370.29
IMPELLER FRONT SHROUD CLEARANCE [in]	0.020
IMPELLER REAR SHROUD CLEARANCE [in]	0.020
INLET PRESSURE [PSIA]	18.5
INLET BYPASS FLOW RATE [%]	0
DESIGN FLOW RATE [GPM]	0
INLET Cu [ft/s]	
INLET TEMPERATURE [R]	

| H-Help | E-End | M-Main menu | P-Previous screen | N-Next element |

Figure 4.10. Impeller operating conditions input screen.

CPAC MENU 1.2.2.2

OPERATING CONDITIONS (ELEMENT #1:INDUCER)

IMPELLER TIP DIAMETER [in]	1.873
IMPELLER HUB DIAMETER [in]	1.873
INLET PRESSURE [psia]	0
INLET BYPASS FLOW RATE [%]	0
INLET Cu [ft/s]	
INLET TEMPERATURE [R]	

| H-Help | E-End | M-Main menu | P-Previous screen | N-Next element |

Figure 4.11. Inducer operating conditions input screen.

Fluid Properties

One enters the fluid properties to the CPAC code through the Fluid properties input screen. Note, it is necessary to enter only the first element's fluid properties, if the remaining elements fluid properties will be calculated by the CPAC code, (variable fluid properties option). Each element's fluid properties should be entered only if one has selected to have variable fixed fluid properties, that is one wishes to enter fixed but possibly different for various elements fluid properties and not use the variable properties method of solution. Again, if selecting fixed properties or using the variable properties method of solution, which incorporates calls to the linked fluid properties code, one need enter only the first node fluid properties. The required fluid properties are the fluid viscosity and the fluid density. If variable fluid properties are called for in the method of solution, the thermodynamics code, GASPLUS, looks up the fluid properties at the state of the fluid, (temperature, and pressure), and uses these properties in the head and flow rate calculations. Figure 4.12 shows the CPAC fluid properties input screen for an inducer element.

```
CPAC                                              MENU 1.2.2.3.2



         FLUID PARAMETER (NODE # 1)

         DENSITY [lb/ft^3]        4.37
         VISCOSITY [ft^2/s]       0.000002




| H-Help | E-End | M-Main menu | P-Previsous screen | N-Next node |
```

Figure 4.12 Inducer fluid properties input screen.

Mapping Parameters

Once the geometry and the operating conditions have been input, it is necessary to select which area or areas of the pump's operating envelop which are of interest from a performance prediction standpoint. This input option has several parameters which give the user many options for predicted performance solutions. One may chose 1 to 10 mass or volume flow rates for 1 to 10 different pump speeds. This can lead to a maximum of 100 predicted operating points of solution for 1 calculation run. This number can be increased simply by changing the appropriate storage array parameters which can be determined from appendix A, the program technical information, and changing some of the counters internal to the code. Figures 4.13 and 4.14 show the volume flow rate and impeller speed input screens respectively. It is not necessary to input both the volume and the mass flow rates, the program uses the mass flow rate for all of the internal program calculations. If the volume flow rates are input, the program converts them to mass flow rates based on the input fluid density. If both the volume and mass flow rates are input, the program will use the input mass flow rate values, and neglect the volume flow rates.

Therefore if both are input, it is necessary to be sure that the mass flow rates are correct. The volume flow rate input option is a convenience to the user since volume flow rates are a more normal working unit. This concludes the input section concerning pump modeling.

```
CPAC                                                  MENU 1.2.2.4.1

     VOLUMETRIC FLOW RATES[GPM] (ELEMENT # 1:INDUCER)

          1)     7.95
          2)     9.54
          3)    11.13
          4)    12.72
          5)    14.31
          6)    15.90
          7)    17.49
          8)    19.08
          9)    20.67
          10    22.26

| H-Help | E-End | M-Main menu | P-Previous screen | N-Next element |
```

Figure 4.13. Inducer volume flow rate input screen.

```
CPAC                                                  MENU 1.2.2.4.3

     IMPELLER SPEED [RPM] (#1 IS DESIGN SPEED)

          1)      74000
          2)      96000
          3)     105000
          4)          0
          5)          0
          6)          0
          7)          0
          8)          0
          9)          0
          10)         0

     | H-Help | E-End | M-Main menu | P-Previous screen |
```

Figure 4.14 Impeller speed input screen.

4-4.1 Running CPAC

Once the model input geometry, operating conditions and mapping parameters are entered into the program either interactively on-line, or read in from a previously edited input file, one needs to select the run condition from the program run menu. This menus is shown in Figure 4.15.

```
CPAC                                                    MENU 2

                    CALCULATION OPTIONS

                    ENTIRE PUMP RUN
                    SINGLE/MULTIPLE ELEMENT(S) RUN


         | H-Help | E-End | M-Main menu | P-Previous screen |
```

Figure 4.15. CPAC Run options menu screen.

The run menu offers 2 choices to the user:

1. Calculate all the elements in the model, and
2. Calculate single or multiple elements.

If option 1 is selected, the program immediately solves for the desired input conditions. If option 2 is selected, the program prompts for which elements in the model to solve for, as well as prompting for the method of tangential velocity input, as shown in Figure 4.16.

```
CPAC                                              MENU 2

              CALCULATION OPTIONS

            ENTIRE PUMP RUN
            SINGLE/MULTIPLE ELEMENT(S) RUN


                ----------------------------------------------
                ACQUIREMENT OF INLET Cu

                Cu FROM PUMP CALCULATION
                Cu FROM USERS INPUT FILE
                ----------------------------------------------

       | H-Help | E-End | M-Main menu | P-Previous screen |
```

Figure 4.16. Single/Multiple element selection menu screen.

The tangential velocity input method is required whenever single or multiple elements are calculated because the computer is unable to discern the element connectivity, (because some of the elements in the configuration sequence may not be selected for calculation). With unknown connectivity, the tangential velocity cannot be transferred from one element to the next while satisfying the conservation of angular momentum equation, which is required for the one-dimensional theory assumptions for fluid flow in a space of revolution. There are two tangential velocity input methods:

1. Defined from the user or,
2. Calculated from an entire pump run.

In the latter, the values are taken from an entire pump run, performed when this selection is made, and then the program output simply displays only the elements selected in the single/multiple run mode. This is the suggested method if several elements are selected, and are not all connected.

If the tangential velocity is to be user defined, (option 1), the values must be input at the selected element's operating conditions input menu. The program then uses these values in calculating the element's predicted losses and performance.

Once the method of tangential velocity input has been selected, the program prompts for which elements to calculate. A menu displays the current input pump model configuration, and prompts the user to select the element or elements to perform the calculations on. The elements selected are then displayed marked with an asterisk (*). **It is necessary to be sure that the tangential velocity values have been input at the elements operating conditions menu.** When all of the elements have been selected, the user exits the menu and the program begins calculations. A message at the top of the screen notifies the user when all calculations have been completed, and prompts for the next command, which is most likely to be to transfer to the Main menu and select the program output options.

4-4.2 CPAC Output Options

Now that the program has been run and the pump performance calculated, the predicted performance can be analyzed by various methods. When the program output menu item is selected, the program displays several methods for output display. These are shown in Figure 4.17.

```
CPAC                                              MENU 3

                OUTPUT FORM SELECTION
                TABULAR OUTPUT
                GRAPHIC OUTPUT
                ----------------------
    | H-Help | E-End | M-Main menu | P=Previous screen |
```

Figure 4.17. Program output menu.

These various methods allow for detailed analysis of the programs predicted performance output. The CPAC Output Menu, (Menu 3, Figure 4.17), displays the program output options:

> **Tabular Output:** This option outputs calculation results in tabular form.
>
> **Graphic Output:** This option offers several graphical output options, including the option of comparing test data to the predicted performance data.

The Tabular output menu is used for the output options, and is displayed as Figure 4.18.

> **Ouput to screen:** Displays the program output to the computer screen, and also allows the user to send the screen tabular output to a local printer by simply the "**T**" command key.
>
> **Output to printer:** Writes the output to a specified default printer, shown at the bottom of the menu.

Write output to file: Saves the output to a file. The program prompts for the file name.

Setprn Q name: Allows the user to set the default printer que, for printer output.

After one of the options above is selected, the program displays the various types of outputs available. Each of these outputs are explained by entering the on-line help utility.

```
CPAC                                                        MENU 3
                      OUTPUT FORM SELECTION
                       TABULAR OUTPUT
                       GRAPHIC OUTPUT
                       -----------------------

                            ----------------------------------------
                            DEVICE SELECTION
                            OUTPUT TO SCREEN
                            OUTPUT TO PRINTER
                            WRITE OUTPUT TO A FILE
                           ------------------------------------------
                           SETPRN Q NAME(Q=GLE1)
                           ------------------------------------------

               | H-Help | E-End | M-Main menu | P-Previous screen |
```

Figure 4.18. Tabular output device selection menu.

Once the Output device type has been selected, the output parameter selection is displayed this is illustrated in Figure 4.19. This menu shows the parameters available for output. Although this menu shows the tabular output parameters, the output parameters are common for each type of output selected, (tabular, graphical, or write to file).

Note: File Saving and Printing

If one wishes to save the output to a file, a menu simply prompts the user for a file name under which to store the output data (the name must be less than 20 characters), and then displays the options above for specific parameter selection to be output. This allows the user to chose different types of output parameters.

When one wishes to print the output, a menu screen lists all of the printer queue names currently available for output of calculation results. The program prompts for an option which may consist of a number 1-15, which will then result in that printer number being read into memory. When one selects a printer number which was already available as a printer option, that number is displayed marked with an "*". If one wishes to use a different printer device, one may choose any available number, (an empty number up to 15), and enter the printer queue name, and optional printer location. To delete a printer option, select the D-delete command key and enter the option number to delete.

```
CPAC                                                MENU 3.1.1

                 TABULAR OUTPUT TO SCREEN

                 PUMP MODEL CONFIGURATION
                 ELEMENT GEOMETRY
                 OPERATING CONDITIONS
                 FLUID PARAMETERS
                 LEAKAGE OUTPUT
                 NODAL VELOCITIES
                 NODAL FLUID FLOW ANGLES
                 NODAL PERFORMANCE
                 ELEMENT LOSSES
                 ELEMENT PERFORMANCE
                 OVERALL PUMP PERFORMANCE
                 OUTPUT ALL OF THE ABOVE
                 ------------------------------------
                 TITLE OF OUTPUT
                 COMMENTS ON OUTPUT

        | H-Help | E-End | M-Main menu | P-Previous screen |
```

Figure 4.19. Parameter selection menu.

When the desired parameter has been selected from the parameter output menu, the program output is displayed. The program output display may have several command key options shown as available, some output will require several screens for display, these can be traversed by using the appropriate command keys of **RTN-Next**, or **P-Previous**, as shown in Figure 4.20. The displayed screen can also be sent to the local printer by selecting the **T-Print** Command key. The **L-Return to List** command key returns to the Parameter selection menu shown in Figure 4.19.

CPAC XLR134

ELEMENT PERFORMANCE
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
9.15	0.09	124074.	0.7857	1.2212	0.6434	8945.5	156.5	0.0
10.75	0.10	145809.	0.7873	1.1220	0.7017	8963.8	157.4	0.0
12.36	0.12	167577.	0.7888	1.0539	0.7484	8981.1	158.5	0.0
13.97	0.14	189381.	0.7903	1.0060	0.7856	8998.3	159.8	0.0
15.58	0.15	211219.	0.7918	0.9717	0.8149	9015.3	161.4	0.0
17.19	0.17	233091.	0.7933	0.9470	0.8377	9032.1	163.1	0.0
18.81	0.18	254993.	0.7947	0.9292	0.8553	9048.8	165.0	0.0
20.42	0.20	276927.	0.7962	0.9165	0.8688	9065.2	167.2	0.0
22.04	0.21	298888.	0.7976	0.9075	0.8789	9081.5	169.5	0.0
23.66	0.23	320877.	0.7990	0.9013	0.8865	9097.5	172.1	0.0

| E-End | M-Main menu | P-Previous | RTN-Next | T-Print | L-Return to list |

Figure 4.20 CPAC tabular output display screen.

4-5.0 Graphic Output Selection

When the graphic output form has been selected, a menu asks the user to enter the X-axis variable and Y-axis variable. Currently, there are 3 variables for the X-axis and 7 variable categories for the Y-axis. These are shown in Tables 4.4 and 4.5.

Table 4.4 X Variables

Volume Flow Rate
Mass Flow Rate
Flow Coefficient

Table 4.5 Y Variables

Nodal Velocities
Nodal Flow Angles
Nodal Performance
Element Losses
Element Performance
Leakage Output
Overall Performance

The Y variable categories are further broken down into several options. these are listed in Table 4.6.

Table 4.6. Y Variable Category options.

Category	Options
Nodal Velocities	C, Cu, Cm, W
Nodal Flow Angles	α, β, deviation
Nodal Performance	Total H, Total P, Static P, T
Element Losses	Incidence, Friction, Diffusion, Total
Element Performance	H-coef, P-coef, P-recovery,H, P, ΔT
Leakage Output	Mass flow rate, Power Loss coef
Overall Performance	ψ, Φ, η, Total H, P, outlet T

Where:

ψ = Head Coefficient
Φ = Power Coefficient
η = Efficiency
H = Head
P = Pressure
T = Temperature

Once the X and Y axis variables are selected, one chooses which element to graph, the inlet or discharge node, then the corresponding pump speed, if several speeds were calculated. There then follows additional menus which allow one to customize the graphical output, as discussed below.

One menu prompts for the user to setup display attributes including limits of drawing (i.e. Xmin, Xmax, Ymin and Ymax), title of drawing, labels of X-Y axes and setting grid on or off. When option 1 is selected, the program uses default attributes for drawing. If one wants to use his/her own attributes for drawing, option 2 can be selected.

Menu 3.2.2 prompts for the user to select a graphic output device which can be a DEC terminal, a Tek terminal or a HP plotter. Once a device is selected, the program will graph the data to the device. For some devices, a device queue name is required. In this case, one can select a queue name which is a valid device, by selecting changing queue name option to specify the user desired queue name.

Menu 3.2.1.2 allows the user to specify his/her own attributes for graphing. Option 1 allows the user to change the limits the graph, (Xmin, Xmax, Ymin, Ymax). Option 2 allows the user to specify the desired title and label on the graph. Option 3 allows the user to set the grid on or off. The default is off. Once the changes have been selected, the user must select the N-Next screen command key to move on to the next menu.

If the graphic output of nodal performance was chosen, a node is required as input. The user can simply enter the node number which is listed on the right of the menu screen.

---

5. CPAC EQUATIONS

5-1.0 Empirical equations and experimental coefficients

The CPAC code calculation method is to solve for the velocity triangles at each element node based on the modeled pump geometry, flow rates and operating conditions. Once the velocity triangle components are known, the theoretical or Euler head is calculated followed by the associated element losses at design and off-design conditions. The theoretical input head and the predicted losses thus provide the predicted output head, therefore the element efficiencies can be calculated. This information serves as the performance prediction output of the program. The major calculation equations are presented in the next sections while a detailed version of all the program equations are presented in appendix B.

5-1.1 General Equations

The CPAC code performs the required calculations for each element in the following order:

1. Element area calculations
2. Element diameter (rms) calculations
3. Element velocity (rms) calculations
4. Element flow calculations
5. Element flow coefficient calculations
6. Element fluid velocity triangle (rms) calculations.

Area Calculation:
$$A = \frac{1}{2} \pi \, w \, (D_{tip} + D_{hub}) \tag{5.1}$$

RMS Diameter Calculation:
$$D_{rms} = \sqrt{(D^2_{tip} + D^2_{hub}) / 2} \tag{5.2}$$

RMS Velocity Calculation:
$$U_{rms} = \frac{D_{rms} \, N}{229.0} \tag{5.3}$$

Weight Flow Calculation: $$WT = \frac{Q\,\rho}{448.765} \tag{5.4}$$

Flow Rate Calculation: $$Q_{cbft} = \frac{WT}{\rho} \tag{5.5}$$

Flow Coefficient Calculation: $$\varphi = \frac{144\ Q_{cbft}}{V_{tip}\ A_{flow}} \tag{5.6}$$

Where:

$$A_{flow} = A\,B\ \frac{Z\ T_n\ w}{\sin(\beta_{rms})} \tag{5.7}$$

5-1.2 Velocity Triangle Calculations

The following equations present ways that the various velocity triangle components are calculated for the pump elements. These are the general equations and it is necessary to note that various elements may have slight differences in the equations. Each elements detailed equations are given in appendix B.

Fluid Meridional Velocity Calculation: $$C_{m\,rms} = \varphi\ V_{tip} \tag{5.8}$$

Substituting φ $$C_{m\,rms} = \frac{144\ Q_{cbft}}{A_{flow}} \tag{5.9}$$

Once these independent values are calculated, the dependent values are then calculated using the previous elements parameters. The next calculations are the absolute rms fluid velocity and the absolute rms fluid tangential velocity component. The tangential component is calculated using a conservation of angular momentum approach:

Fluid Tangential Velocity Component: $$C_{ui\,rms} = \frac{C_{u\,i-1\,rms}\ D_{i-1\,rms}}{D_{i\,rms}} \tag{5.10}$$

Absolute Fluid Velocity: $$C_{rms} = \frac{C_{m\,rms}}{\sin(\alpha)} \tag{5.11}$$

When these parameters have been calculated, the element losses and other performance parameters can be calculated.

5-1.3 Loss Equations

The following sections present the various loss equations which are incorporated into the CPAC code. Each equation has been researched to a referenced theoretical base. The references are listed where appropriate.

Incidence Loss Calculations

The incidence loss or "shock loss" is calculated using the following empirical equations. Note that this form takes the relative angle of the blades and fluid into account to determine the coefficient K_{inc}.

Incidence Loss:

$$\phi_{inc} = \frac{K_{inc}}{2\ g} \frac{S_1{}^2}{V_{tip}} \tag{5.12}$$

where

$$\frac{S_1}{V_{tip}} = \frac{C_{m\ rms}}{V_{tip}} \left|\cot\beta_{b1} \quad \cot\beta_{f1}\right| \tag{5.13}$$

with

$$\begin{aligned} K_{inc} &= 0 \quad \text{for} \quad \left|\beta_{b1} \quad \beta_{f1}\right| \leq 2 \\ K_{inc} &= 0.3 \quad \text{for} \quad \left|\beta_{b1} \quad \beta_{f1}\right| \mathrm{f} \ \ 2 \end{aligned} \tag{5.14a,b}$$

In these equations the subscript 1 denotes the inlet to the element.

Diffusion Loss Calculations

The diffusion losses are estimated by the calculation of a diffusion factor D, modified by a correction factor determined from the type of pump element under evaluation. The diffusion factor is determined from

$$D = 1 - \frac{W_2}{W_1} + \frac{W_1 \quad W_2}{2\ \sigma W_1} \tag{5.15}$$

The diffusion loss coefficient then is calculated empirically by

$$\phi_{dif} = K_{dif}\ D^N \tag{5.16}$$

The values for K and N are element dependent and are listed in table 5.1. It should be noted that the diffusion loss calculated for the volute, and downcomer has been added to the code at R.I.T. The form is referenced from Stirling, (see reference 12). The correction factors K and N have been selected based on experience, however, they may be modified depending on further investigation.

Table 5.1 Diffusion loss empirical parameters.

Element	K	N
Inducer	0.05	2
Stator	0.03	3
Impeller	0.03	3
Diffuser	0.03	3
Volute	0.02	2
Downcomer	0.03	3

Skin Friction Loss Calculations

The final major pump loss calculated is the skin friction loss. This loss is calculated for the element types: inducer, stator, impeller, vaned diffuser, vaneless diffuser, volute, turning channel, downcomer, and return passage. The loss calculation is strongly dependent on the friction coefficient, which is calculated by determining the Reynolds number and the hydraulic diameter, then incorporating the Moody diagram to select the appropriate friction coefficient. The following equations are used in the program to calculate the element skin friction loss coefficients:

$$\phi_{skf} = \frac{f}{4}\frac{L}{D_h}\left[\frac{W_1^2}{V_{tip}^2} + \frac{W_2^2}{V_{tip}^2}\right] \tag{5.17}$$

The friction coefficient is then a function of the Reynolds number and roughness as noted above,

$$f = F(Re, \frac{e}{D_h}) \tag{5.18}$$

where

$$Re = \left[\frac{W_1^2}{V_{tip}^2} + \frac{W_2^2}{V_{tip}^2}\right]\frac{D_h V_{tip}}{2\,\upsilon} \tag{5.19}$$

where the hydraulic diameter, D_h is: $D_h = \frac{4}{2}\left[\frac{A_1}{P_1} + \frac{A_2}{P_2}\right]$ (5.20)

and

$$A_i = \left[\frac{\pi}{Z_i} D_{i\,rms} \sin\beta_{bi} (B_i - T_{ni})\right](D_{tipi} - D_{hubi})$$

$$P_i = \left[2\,(D_{tipi} - D_{hubi}) + \frac{\pi}{Z_i}(D_{tipi} + D_{hubi})\sin\beta_{bi} - 2T_{ni}\right] \tag{5.21a ,b}$$

$i = 1,2$

Volute Momentum Loss Calculation

The scroll momentum loss is determined from the following equations:

$$\phi_{scm} = K_{scm}\left[\frac{Cu_{i\,rms}}{V_{tip}}\right]^2 \left|\frac{A_{throat} - A_{scm}}{A_{throat}}\right|^2 \qquad (5.22)$$

where A_{scm} is the area determined from D_{scm} given below, and $K_{scm} = 0.5$.

$$D_{scm} = 2\sqrt{D_{throat}\, w_i \tan\alpha_i} \qquad i = \text{inlet} \qquad (5.23)$$

Mechanical Loss Calculations

The program calculates a variety of mechanical losses associated with the various types of impellers. These include disc friction losses, wear ring losses, leakage losses, and Recirculation losses.

The horsepower loss due to disc friction, and the capacity losses due to leakage flow rate through the impeller affect the incidence, skin friction and diffusion losses. These losses are modeled with leakage elements. The loss coefficients are calculated from the following equations:

The horsepower losses are of the form: $\quad Hp_d = K\, D^2 \rho\, U_{rms}^3 \qquad (5.24)$

presented in Stepanoff[2], where

K = correction coefficient
D = impeller diameter
ρ = fluid density
U = impeller peripheral velocity

In CPAC,

$$U_{rms} = V_{tip}$$

$$D = \frac{\left[D_{rms2}^5 - D_{rms1}^5\right]}{D_{rms2}^3} \qquad (5.25\text{ a-c})$$

where

$$K = \frac{[9\rho]\,[0.5]\,[24]\,[12^5]}{550\ g}$$

The leakage losses are of the following form:

$$Q_{leakage} = C_{wr}\, A_{wr}\sqrt{2\, g\, H_{wr}} \qquad (5.26)$$

where A_{wr} = Leakage flow area
C_{wr} = Wear ring loss coefficient
H_{wr} = Head drop across wear ring.

Note: C_{wr}, and A_{wr} change depending on the impeller type.

Once these losses have been computed, the subroutine modifies the flow rates, and other flow rate dependent parameters, due to the losses and leakages of the impeller. These modifications are as follows:

Flow Rate Modification: $Q_{cbft} = Q_{cbft} + Q_{leakage\ rear} + Q_{leakage\ front}$ (5.27)

Flow Coefficient Calculation:

$$\varphi = \frac{144\ Q_{cbft}}{V_{tip}\ A_{flow}}$$

where (5.28 a,b)

$$A_{flow} = A\ B \quad \frac{Z\ Tn\ w}{\sin \beta_{rms}}$$

Recirculation Loss Calculations

The recirculation loss is calculated as follows:

"An empirical equation has been developed based on test data that gives the flow coefficient of a pump at the maximum efficiency point and is a function of the **head coefficient** at the maximum efficiency φ_{des} and **blade angle** at discharge of impeller, β_{b2} and minimum blade number for maximum efficiency Z_2. This equation is:

$$\phi_{2des} = \frac{K\ \varphi_{des} \sin \beta_{b2}}{Z_2} \qquad (5.29)$$

where K = 7.03 Empirically.

The recirculation loss is considered to be zero at the maximum efficiency point. At zero flow, the required pump horsepower due to recirculation is a constant G times the design pump power required.

$$\Delta P_{crec} = 0.0 \quad \text{at} \quad \phi_2 = \varphi_{2des}$$
$$\Delta P_{crec} = G\ Hp_{[\text{at max }\eta]} \quad \text{at} \quad \phi_2 = 0.0 \qquad (5.30a,b)$$

An empirical equation is then given as:

$$\Delta P_{crec} = \frac{G\ \varphi_{des} \left[\phi_{2des} \quad \phi_2\right]^{3\eta}}{\phi_2\ \phi_{2des}^{2\eta}} \qquad (5.31)$$

where η defines the amount of power loss with ϕ and could possibly be correlated with impeller discharge blade angle. The value G has been found from test data at shutoff or zero flow to be in the range of 0.3 to 0.5."[8]

Once these modifications have been computed, the subroutine returns to the impeller inlet to recalculate all of the above parameters with the modified flow rate values. This iteration is performed three times, (note, the flow rates are not updated after the third iteration, so that the correct flow rates are saved for the final iteration). The value of three for the number of iterations satisfies the convergence criteria of the program. When these values have been computed, the impeller performance can be evaluated.

Impeller Theoretical Head Calculations

In order to correctly evaluate a pumps performance, the theoretical head input by the impeller needs to be calculated. This input head by the impeller is calculated from the velocities.[3]

Theoretical Head Equation:

$$H_{input} = \frac{C_{rms2}^2 \quad C_{rms1}^2}{2\,g} + \frac{V_{tip}^2 \quad U_{rms1}^2}{2\,g} + \frac{W_1^2 \quad W_2^2}{2\,g} \tag{5.32}$$

In the CPAC code, the theoretical head coefficient, is calculated:

$$\psi_{theory} = \frac{\left[V_{tip}Cu_2 \quad U_{rms1}Cu1\right]}{V_{tip}^2} \tag{5.33}$$

where $V_{tip} = U_2$

from which the theoretical head is calculated:

$$Head_{theory} = \frac{\psi_{theory}\, V_{tip}^2}{g} \tag{5.34}$$

5-1.4 Performance Equations

It is important to note that for each element, once all of the losses for that element are calculated, the individual element performance is evaluated.

Total Element Loss: $\text{Total Loss} = \sum \text{All Element Losse}$ (5.35)

Element Euler Head Coefficient: $$H_{Euler} = \frac{U_{rms2}Cu_2 - U_{rms1}Cu_1}{V_{tip}^2} \tag{5.36}$$

Element Actual Head Coefficient: $$H_{Act} = H_{Euler} - \text{Total Losses} \tag{5.37}$$

Element Efficiency: $$\eta_{Element} \frac{H_{Act}}{H_{Euler}} \tag{5.38}$$

6. Results and Discussions

To demonstrate the predictive capabilities and the versatility of the CPAC code, several different pumps have been modeled. The predicted performance values have been compared to actual test data where available. The various pumps selected are of different types, (vaned diffuser, or volute pumps), and include scaled up testers as well as actual cryogenic turbopumps, some include variable fluid properties, as well as various operating speed ranges. The following cases are presented:

1. A scaled-up single stage water test pump of the Mark 49-F liquid hydrogen turbopump.
2. The 3 stage Mark 49-F turbopump with high pressure ratio diffusers and crossovers.
3. The Mark-48 3 stage turbopump is modeled with variable properties.
4. The XLR-134 3 stage liquid hydrogen turbopump.
5. The Pratt & Whitney Advanced Engine Test Bed (AETB).

Each model is presented showing the configuration, and predicted performance. This performance is compared to pump test data where available, which is followed by a discussion of any discrepancies. In addition, full CPAC output summaries are included for several of these cases in Appendic C.

6-1.0 Mark 49-F Water Tester

The development of the Mark 49-F turbopump with high pressure ratio diffusers and crossovers included an extensive test program on a scaled-up single stage pump using water as the test fluid. This water test program provides test data with which the CPAC program can be evaluated. A review of the literature provided from NASA Lewis Research Center provided some of the required input geometric data as well as the operating conditions. The CPAC model configuration is shown in Figure 6.1. The model consists of an **inducer, impeller, vaneless diffuser, vaned diffuser, crossover**, (consisting of a **turning channel** and **downcomer** elements), as well as a **leakage** element to account for impeller shroud and wear ring leakage effects.

The comparison of the CPAC predicted output to the actual test data consists of:

1. Comparison of the inducer static head rise.
2. The inducer and impeller static head rise.
3. The overall stage head and efficiency.

Some of the CPAC predicted output is shown in Tables 6.1-6.3, while the comparison to the test data is shown in Figures 6.2 and 6.3.

CPAC MENU
1.2.1

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET NODE	DISC. NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	VANED DIFFUSER	4	5
5	TURNING CHANNEL	5	6
6	DOWNCOMER	6	7
7	LEAKAGE w/ FS FWR	3	2

| H-Help | E-End | M-Main menu | P-Previous screen | D-Delete | I-Insert |

Figure 6.1. Mark 49-F Scaled-up Water Tester model configuration.

Table 6.1 Inducer element performance - CPAC tabular output.

CPAC mark49-wt

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
291.24	40.50	213327.	0.1257	0.1632	0.7701	368.3	78.8	0.0
350.21	48.70	256520.	0.1151	0.1533	0.7507	337.4	74.4	0.0
407.67	56.69	298606.	0.1036	0.1437	0.7209	303.7	67.8	0.0
465.99	64.79	341324.	0.0907	0.1340	0.6771	265.9	59.0	0.0
524.88	72.98	384463.	0.0765	0.1242	0.6157	224.1	47.8	0.0
583.13	81.08	427129.	0.0611	0.1144	0.5339	179.1	34.6	0.0
640.66	89.08	469268.	0.0447	0.1048	0.4267	131.1	19.3	0.0
698.91	97.18	511933.	0.0269	0.0951	0.2833	79.0	1.7	0.0
757.88	105.38	555125.	0.0130	0.0853	0.0900	38.1	-11.6	0.0
816.13	113.48	597791.	0.0105	0.0755	-0.1668	30.7	-11.1	0.0

Table 6.2 Impeller element performance - CPAC tabular output.

CPAC mark49-wt

ELEMENT PERFORMANCE
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] 6322

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
366.13	50.91	165438.	0.5984	0.7344	0.8149	1754.2	456.0	0.0
424.66	59.05	191885.	0.5936	0.7078	0.8387	1740.1	454.7	0.0
481.51	66.95	217573.	0.5886	0.6899	0.8531	1725.2	452.7	0.0
539.12	74.96	243604.	0.5832	0.6758	0.8629	1709.4	450.5	0.0
597.25	83.05	269871.	0.5776	0.6641	0.8698	1693.1	448.2	0.0
654.72	91.04	295839.	0.5720	0.6543	0.8742	1676.6	445.8	0.0
711.48	98.93	321483.	0.5663	0.6460	0.8766	1660.0	443.5	0.0
768.94	106.92	347447.	0.5605	0.6388	0.8774	1643.0	441.1	0.0
827.11	115.01	373734.	0.5545	0.6325	0.8767	1625.4	438.8	0.0
884.59	123.00	399705.	0.5485	0.6270	0.8747	1607.8	436.6	0.0

Table 6.3 CPAC Overall pump performance prediction.

CPAC mark49-wt

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 6322

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
291.24	40.50	0.0361	0.3235	0.8975	0.3605	977.0	415.1	519.7
350.21	48.70	0.0419	0.3722	0.8612	0.4322	1127.1	476.5	519.7
407.67	56.69	0.0475	0.3987	0.8336	0.4782	1212.9	509.4	519.7
465.99	64.79	0.0532	0.4106	0.8098	0.5070	1257.0	523.5	519.7
524.88	72.98	0.0589	0.4109	0.7882	0.5213	1267.9	522.6	519.7
583.13	81.08	0.0646	0.4017	0.7687	0.5225	1251.6	509.2	519.7
640.66	89.08	0.0702	0.3844	0.7509	0.5120	1212.6	485.4	519.7
698.91	97.18	0.0758	0.3597	0.7339	0.4900	1152.5	451.8	519.7
757.88	105.38	0.0816	0.3277	0.7178	0.4565	1087.8	415.3	519.7
816.13	113.48	0.0872	0.2897	0.7026	0.4123	1042.6	386.8	519.7

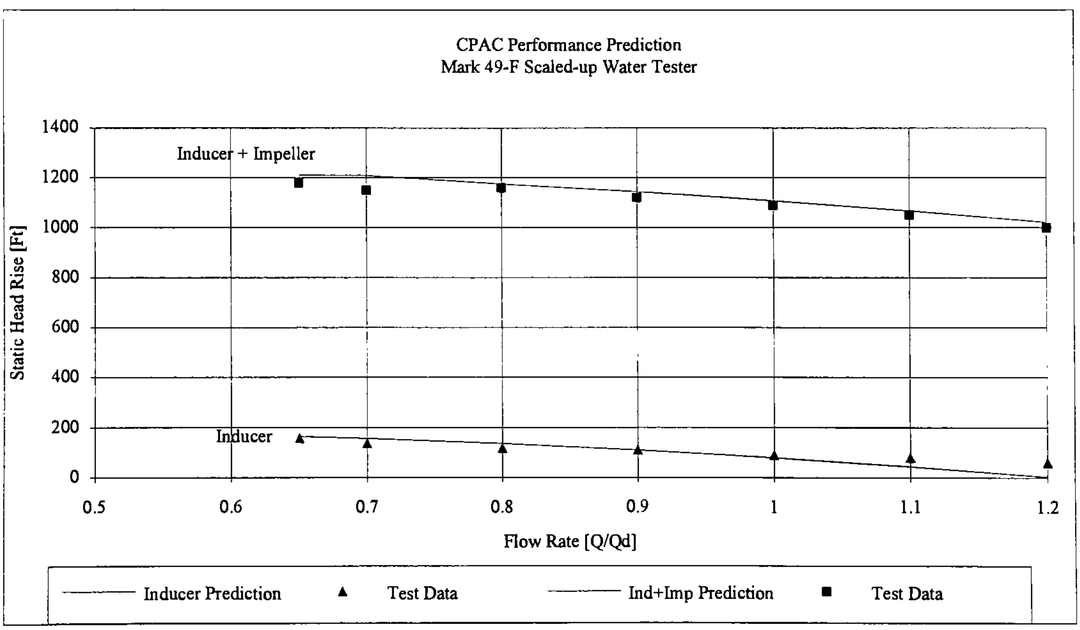

Figure 6.2. Mark 49 Water Tester inducer, impeller static head rise vs flow rate.

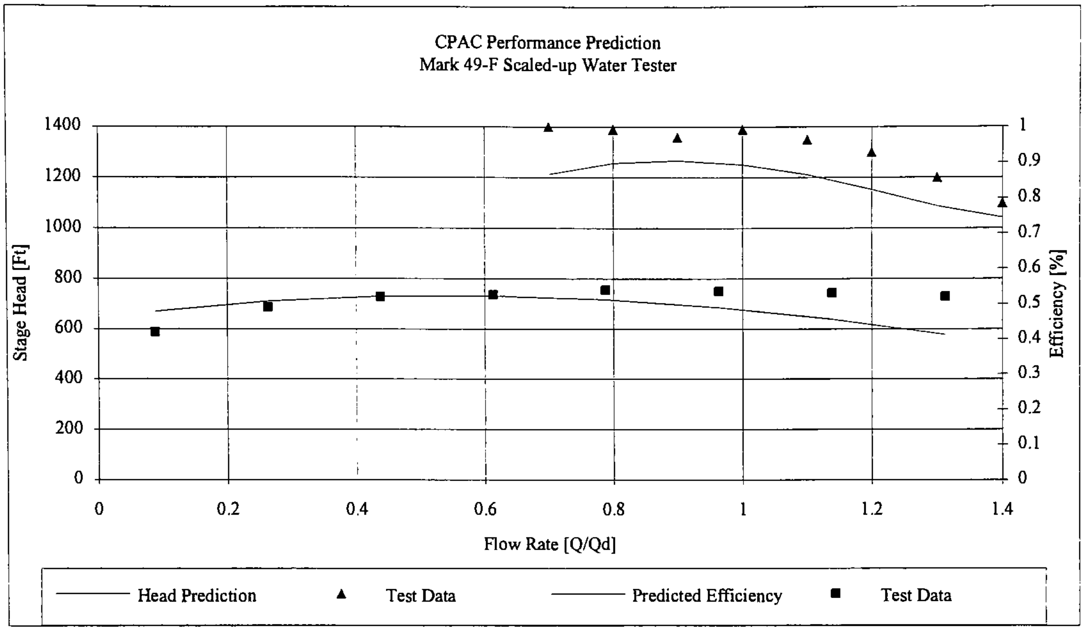

Figure 6.3. Mark 49-F Water Tester stage head, efficiency vs flow rate.

The CPAC program predicts the static head rise for the inducer and impeller elements to within 3% of the available test data as shown in figure 6.2. The overall stage performance is predicted to within 10% of the test data, as shown in figure 6.3. The fact that the overall stage head rise is under predicted by approximately 10% may be a result of poor predictions in the downcomer and turning channel elements. If the calculated losses of the turning channel and downcomer were removed from the CPAC prediction, the CPAC program predicts the design point stage head to within 1%. Currently no loss data is available for the crossover section to validate this assumption. The discrepancies presented here serve to indicate areas where further empirical and test information may improve the prediction performance of the code.

Although some errors in the performance prediction exist, the usefulness of the CPAC program is evident in that it serves to identify inefficiencies in the pump on an individual element basis and acceptably predicts overall performance. The predicted efficiency of the Mark 49-F Water Tester is within 5 percentage points of the test data over a flow rate range of 0.65 < Q/Qd < 1.2.

6-2.0 Mark 49-F 3 Stage Liquid Hydrogen Turbopump

The Mark 49-F 3 stage LH2 turbopump was developed for use on the RS-44 Orbital Transfer Vehicle rocket engine. This pump is unique with respect to the use of high velocity ratio diffusing crossovers between the first and second stages. The CPAC pump model configuration is shown in figure 6.4. The first stage includes the **inducer** followed by an **impeller** and **vaneless diffuser**. The high velocity ratio diffusing crossover is modeled as **vaned diffuser, turning channel** and **downcomer elements**. This crossover then leads to the second stage, which consists of an **impeller** followed by a **vaneless diffuser** and the second stage crossover, (again modeled as **vaned diffuser, turning channel** and **downcomer** elements). The third stage is modeled as an **impeller** element followed by a **vaneless diffuser** and a **single discharge volute**. The configuration then shows several leakage elements, which are connected to the various impellers to account for shroud leakage effects.

CPAC Mark 49 LH2

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET NODE	DISC NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	VANED DIFFUSER	4	5
5	TURNING CHANNEL	5	6
6	DOWNCOMER	6	7
7	IMPELLER	7	9
8	VANLESS DIFFUSER	9	10
9	VANED DIFFUSER	10	11
10	TURNING CHANNEL	11	12
11	DOWNCOMER	12	14
12	IMPELLER	14	15
13	VANLESS DIFFUSER	15	16
14	1-DISC. VOLUTE	16	18
15	LEAKAGE w/ FS FWR	3	2
16	LEAKAGE w/ FS FWR	9	8
17	LEAKAGE w/ FS FWR	15	14
18	1-DISC. EXIT DIFF.	18	19
19	LEAKAGE w/ RS RWR	7	3

Figure 6.4 Mark 49-F Pump CPAC model configuration.

This model was run to predict the performance of the Mark 49-F turbopump, the pump for which the scaled-up Mark 49 water tester was built and evaluated. Lack of available test data is unfortunate, however, the data does compare well to the scaled water tester data presented in section 6-1.0.

This particular model was run at various impeller speeds, as well as utilizing the CPAC programs link to a thermodynamics code which calculates fluid properties throughout the pump. The predicted overall performance for the design speed of 110,000 rpm is presented in Table 6.4. The predicted performance for various speeds is shown in figure 6.5.

Table 6.4 Mark 49-F design speed overall pump performance prediction.

CPAC Mark 49 LH2

OVERALL PUMP PERFORMANCE
IMPELLER SPEED[RPM] = 110000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
233.07	2.37	0.0326	1.0139	2.3699	0.4278	112382.0	3559.4	82.5
282.83	2.89	0.0397	1.1801	2.2896	0.5154	131241.8	4180.3	90.0
322.67	3.31	0.0453	1.2582	2.2451	0.5604	140426.0	4483.2	93.7
362.03	3.71	0.0507	1.3044	2.2079	0.5908	146097.9	4669.5	96.1
401.98	4.13	0.0563	1.3282	2.1716	0.6116	149525.8	4787.2	97.4
440.97	4.54	0.0617	1.3334	2.1370	0.6240	150977.0	4840.9	97.7
480.74	4.95	0.0673	1.3231	2.1022	0.6294	150665.1	4838.4	97.3
520.46	5.37	0.0728	1.2999	2.0684	0.6284	149182.6	4797.5	96.3
559.07	5.78	0.0782	1.2659	2.0362	0.6217	146583.5	4721.3	94.9
656.77	6.87	0.0922	1.1343	1.9567	0.5797	135565.5	4417.8	87.7

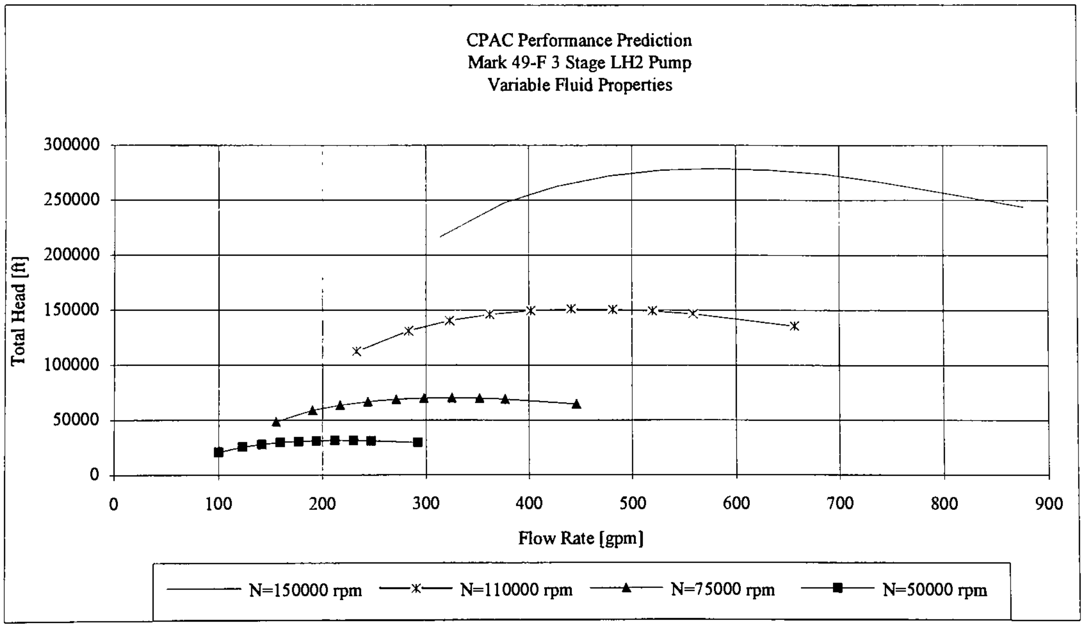

Figure 6.5 Mark 49-F Predicted total head vs flow rate, various impeller speeds.

6-3.0 Mark-48-F Small high-pressure 3 stage turbopump.

The third case study is the Mark 48-F Liquid Hydrogen Turbopump. The Mark 48 pump is a high pressure, low capacity liquid hydrogen turbopump designed by the Rocketdyne Division of Rockwell International. This pump was intended to meet the requirements for small, high-performance, reusable, versatile, staged-combustion and expander-cycle rocket engine applications. The design speed for this pump is 9947 rad/sec, (95000 rpm). The remaining design parameters are listed in Table 6.5.

Table 6.5 Mark 48 design parameters.

Inlet Pressure	**71 [psia]**
Inlet Temperature	**38-41 R**
Discharge Pressure	**4560 [psia]**
Mass Flow Rate	**6.04 [lb/sec]**
Number of Stages	**3**

The Mark 48-F turbopump is required to operate at long durations, with long coast times between multiple starts, including off-design point operation. Therefore off-design performance analysis is a necessity that must be accomplished through expensive testing and/or reliable predictive methods. This model was chosen to demonstrate the wide range of off-design performance prediction capability that the CPAC code exhibits.

The off-design performance prediction of the CPAC code can aid in the development of such a pump. The CPAC pump model configuration is shown in Figure 6.6. The first stage includes an **inducer** element followed by an **impeller** element including modeled **leakage**. The first stage impeller is followed by a **vaneless diffusing section** and a **vaned diffuser**. The stage crossover consisted of a **turning channel**, a **downcomer** and another **turning channel**. This turning channel leads into the second stage **impeller** and **leakage** elements, the **vaneless** and **vaned diffuser** followed by another stage crossover, (**turning channel, downcomer** and **turning channel**). The third stage **impeller** and **leakage** are followed by a **vaneless diffuser, a vaned diffuser** and a **single discharge volute**. The results of the CPAC performance prediction compared to actual test data is shown in Table 6.6, and Figure 6.7.

```
CPAC                                                Mark48 LH2

                         PUMP MODEL CONFIGURATION

          ELEMENT            ELEMENT               INLET        DISC
          NUMBER              TYPE                 NODE         NODE
             1       INDUCER                         1            2
             2       IMPELLER                        2            3
             3       LEAKAGE w/ FS FWR               3            2
             4       VANLESS DIFFUSER                3            4
             5       VANED DIFFUSER                  4            5
             6       TURNING CHANNEL                 5            6
             7       DOWNCOMER                       6            7
             8       TURNING CHANNEL                 7            8
             9       IMPELLER                        8            9
            10       LEAKAGE w/ FS FWR               9            8
            11       VANLESS DIFFUSER                9           10
            12       VANED DIFFUSER                 10           11
            13       TURNING CHANNEL                11           12
            14       DOWNCOMER                      12           13
            15       TURNING CHANNEL                13           14
            16       IMPELLER                       14           15
            17       LEAKAGE w/ FS FWR              15           14
            18       VANLESS DIFFUSER               15           16
            19       VANED DIFFUSER                 16           17
            20       1-DISC. VOLUTE                 17           18
```

Figure 6.6 Mark 48 CPAC model configuration.

Table 6.6 Mark 48 CPAC prediction - test data comparison.

Speed = 95000 rpm					Speed 75000 rpm				
Test Data		CPAC Prediction			Test Data		CPAC Prediction		
m [lb/sec	P [psia]	m [lb/sec	P [psia]	% diff.	m [lb/sec	P [psia]	m [lb/sec	P [psia]	% diff.
3.9	5025	4.0	5078	1.0	3.3	3150	3.5	3163	0.4
4.3	5100	4.5	5075	-0.5	4.0	3250	3.9	3139	-3.4
5.0	5220	4.9	5036	-3.5	4.8	3100	4.7	3030	-2.3
5.3	5200	5.4	4965	-4.5	5.8	2950	5.1	2948	-0.1
6.0	5030	5.9	4863	-3.3	5.9	2900	5.5	2748	-5.2
Speed = 60000 rpm					Speed 45000 rpm				
Test Data		CPAC Prediction			Test Data		CPAC Prediction		
m [lb/sec	P [psia]	m [lb/sec	P [psia]	% diff.	m [lb/sec	P [psia]	m [lb/sec	P [psia]	% diff.
2.8	2050	2.8	2024	-1.3	2.3	1150	2.3	1130	-1.8
3.4	2000	3.4	1980	-1.0	2.8	1100	2.8	1091	-0.8
3.8	1900	3.8	1939	2.1	3.2	1050	3.3	1025	-2.4
4.0	1850	4.1	1887	2.0					
4.5	1700	4.4	1823	7.2					

The CPAC performance prediction is within 7.2% from 53% of the design pump speed (45000 rpm) up to design speed (95000 rpm), Table 6.6. The design speed (95000 rpm) performance prediction ranges from +1% to - 4.5% error over a Q/Qd range of 0.8 to 1.2. It is interesting to note that in a general sense, as the operating speed is increased, the difference between the test data and the predicted data also increases. This indicates that as speed increases, the losses are over predicted. Overall the CPAC performance prediction is satisfactory, and does appear to perform better than the predictive code used during the actual testing, (see Figures 6.7-6.8). The loss prediction analysis as well as the recommendation section suggest areas where future modifications may improve the overall code performance.

Table 6.7 Mark 48 CPAC predicted performance, 95000 rpm.

OVERALL PUMP PERFORMANCE
IMPELLER SPEED [RPM] 95000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
254.22	2.48	0.0362	1.8134	6.9204	0.2620	161383.1	4897.3	40.0
304.06	2.96	0.0423	1.8668	6.1337	0.3044	165869.4	5033.4	40.0
354.91	3.46	0.0485	1.9002	5.5384	0.3431	168546.1	5114.5	40.0
405.75	3.95	0.0547	1.9170	5.0799	0.3774	169712.2	5149.7	40.0
456.59	4.45	0.0609	1.9197	4.7151	0.4071	169591.3	5145.9	40.0
507.43	4.94	0.0671	1.9099	4.4167	0.4324	168316.5	5107.0	40.0
558.28	5.44	0.0733	1.8884	4.1666	0.4532	165971.1	5035.7	40.0
609.12	5.93	0.0795	1.8559	3.9529	0.4695	162609.8	4933.5	40.0
659.96	6.43	0.0858	1.8129	3.7673	0.4812	158269.2	4801.5	40.0
710.81	6.92	0.0920	1.7595	3.6037	0.4882	152973.6	4640.6	40.0

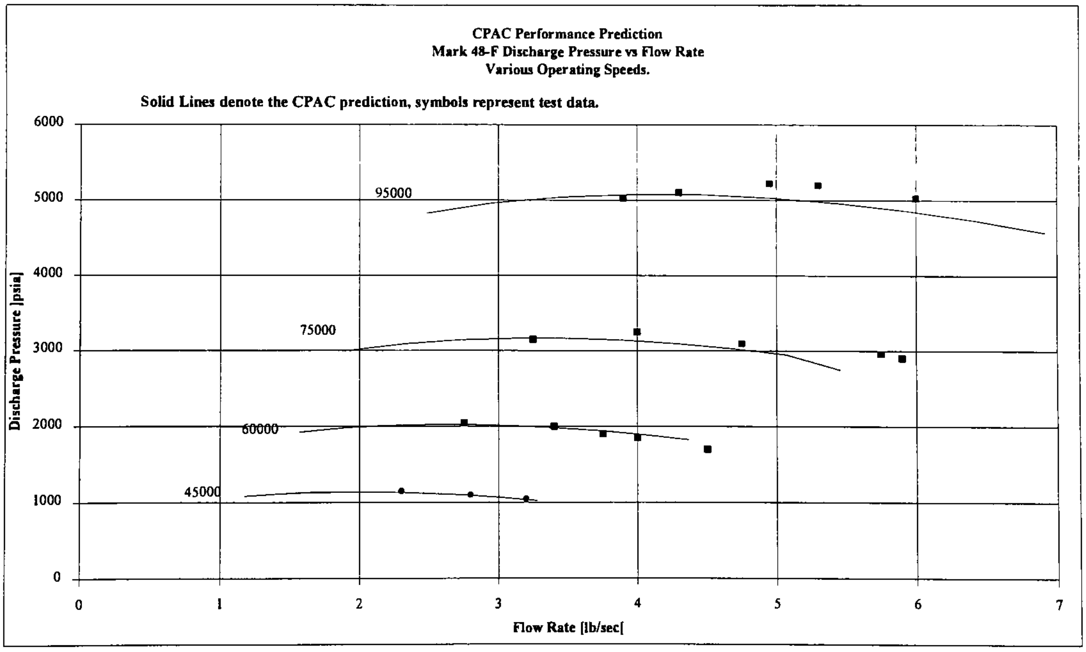

Figure 6.7. Mark 48-F Discharge head vs flow rate.

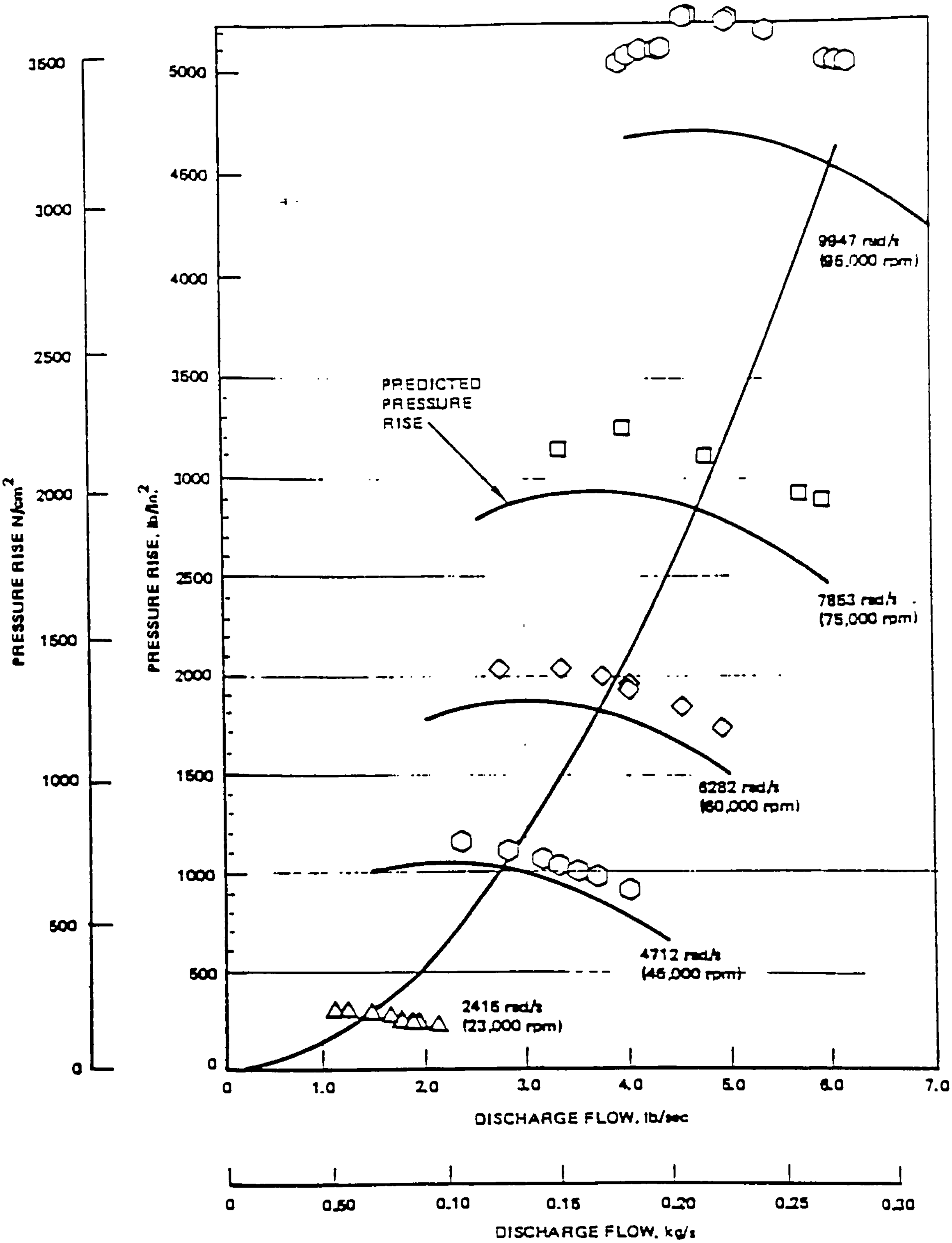

Figure 6.8 Mark 48 performance prediction comparison to test data, unknown code.

6-4.0 XLR-134 Turbopump

The next pump model case considers the XLR-134 Turbopump. This pump is used for low thrust cryogenic engine applications. The predicted performance is compared to test data collected during pump development by the Aerojet Propulsion Division. This case study demonstrates how one may go from a design to a CPAC model and predict performance. Other features of this model are that it shows how leakage flow rates can be modeled relatively accurately, as well as modeling the actual flow rates through the pump.

The XLR134 fuel pump spool #1 CPAC model consists of 3 similar stages. Each stage contains an identical impeller element of tip diameter 1.873 inches. The first stage **impeller** is prefaced with an **inducer**, and followed by a **vaneless diffuser**, and crossover assembly. The crossover assembly is modeled as a **vaned diffuser**, (upcomer), a tu**rning channe**l, and a **downcomer**. The second stage **impeller** follows the first stage downcomer. The second stage is modeled identically as the first stage, without an inducer element. Following the second stage crossover assembly is the third stage **impeller** element, followed by a **vaneless diffuser**, a **single discharge volute**, and a **single discharge ex**it **diffuser**. The geometric parameters for this model match the known values where possible, some of the parameters, such as turning channel and downcomer diameter values were obtained from a previous CPAC model run at NASA Lewis Research Center.

Leakage Modeling

The XLR134 spool #1 has front and rear shroud leakages at the impeller which were modeled to approximate the flow and pressure schematic, (Fig. 6.9). The CPAC leakage elements are modeled as front or rear shroud wear ring leakage elements. These elements require a wear ring diameter, a wear ring clearance, and leakage coefficients as input values. The wear ring diameter used is 0.40 inches; this value was chosen because it was very close to the wear ring diameter shown on the impeller design print of 0.3803 inches. The clearance dimension 0.001 inches is in the range common to pump wear rings of this design. Once these geometric parameters are defined, the leakage coefficients were calculated to give the correct leakage flow rate at the pump design flow rate. These values were calculated by the equation:

$$Q_{leakage} = A_{wr} C_{wr} \sqrt{2G\Delta H}$$

$Q_{leakage}$ is given from the flow/pressure schematic.

A_{wr} is the wear ring area, calculated from the input data.

H is head rise of the impeller element (obtained from an initial single stage calculation run).

G is the gravitational constant.

Solve for C_{wr}.

Some iterations were necessary to zero in on the correct values.

The above procedure was used to model the first stage front and rear shroud leakage of 0.65 and 2.0 gpm respectively; the second stage front and rear shroud leakages were modeled as 0.70 and 0.50 gpm and the third stage front shroud leakage of 0.70 gpm, all at design flow rate. The results of these leakage elements are as follows:

Table 6.8 XLR-134 Leakage Modeling.

Stage	Element	Actual	Modeled
Stage 1	Front Shroud	0.65	0.648
	Rear Shroud	2.00	2.089
Stage 2	Front Shroud	0.70	0.660
	Rear Shroud	0.50	0.516
Stage 3	Front Shroud	0.70	0.660

The Flow and Pressure schematic also show a 1.29 gpm flow rate input to the second stage of the XLR134 spool #1, from the turbine oxidizer pump. This flow rate is modeled as an inlet bypass flow rate to the second stage impeller inlet of -8.11% which corresponds to (1.29/15.90)x100. The value is negative because it is an input bypass flow rate.

There is also a third stage rear shroud leakage of 0.95 gpm at the design flow rate which is modeled as a bypass flow rate of -5.975%,(0.95/15.90)x100. This bypass flow rate occurs at node #13 which is the inlet node of the third stage vaneless diffuser element. This leakage flow rate was modeled as a bypass flow rate because the origin of the flow rate is outside the control area of the pump section schematic which is being modeled, see Fig.4.6.

CPAC Prediction Performance

The prediction performance of the CPAC program is very good at the design point, as shown by the test data comparison graph Fig. 6.9, (the design point is at Q/N = 0.00024 gpm/rpm). The predicted pump head and discharge pressure of 19692.8 ft and 595.5 psi are 0.5 % and -1.4 % different than the tested values shown in table 6.9. At off-design conditions, the prediction performance is not as good. The CPAC code tends to under predict the test data at flow rates lower than the design flow rate, and over predict the test data at flow rates above the design flow rate, as shown in the graphs.

Table 6.9 XLR-134 Design Parameters.

Head rise per stage	6561 [ft] Total = 6561x3=19683 [ft]
Number of stages	3
Discharge Pressure	604 [psia]
Flow Rate	0.153 [lb/sec]
Speed	74000 [rpm]
Efficiency	51 [%]
Impeller Diameter	1.873 [in]
Impeller Tip Speed	605 [ft/sec]
Inlet Temperature	37.8 [R]
Inlet Pressure	18.5 [psia]

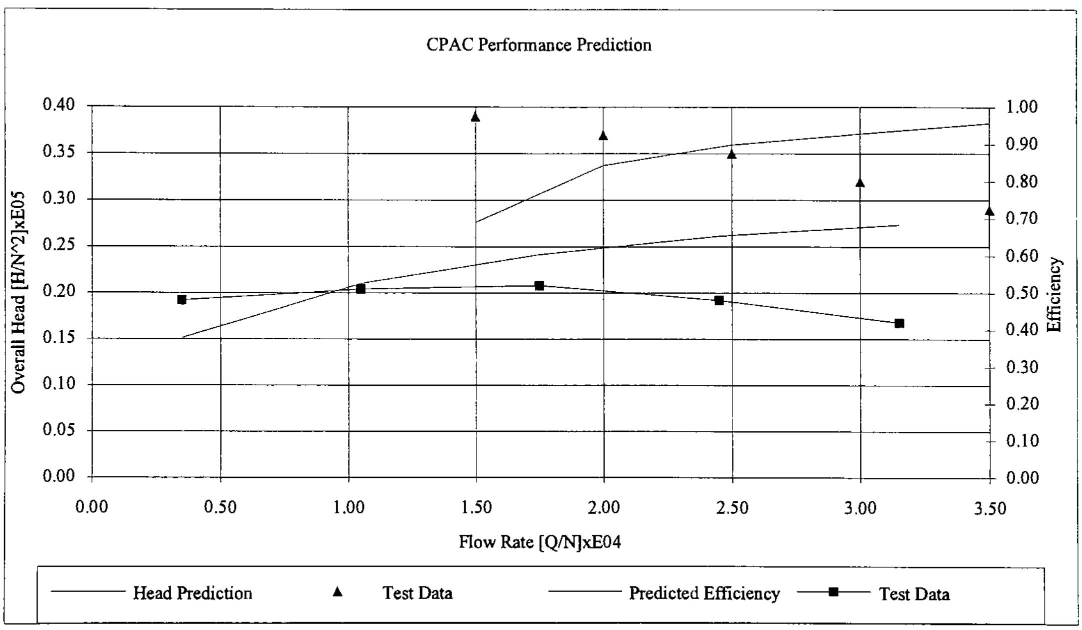

Figure 6.9. Pump head and efficiency vs flow rate (XLR-134).

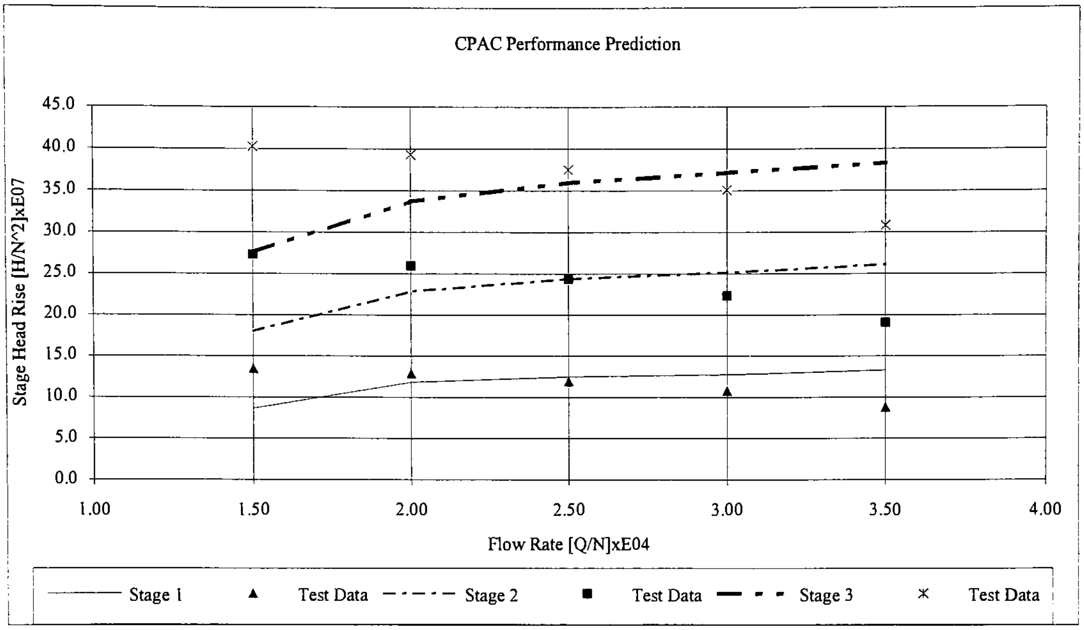

Figure 6.10 XLR-134 Stage performance.

6-5.0 Advanced Engine Test Bed (AETB) Turbopump

The AETB is a volute type turbopump developed at Pratt and Whitney. This pump was developed for throttling capabilities for future space missions like the Mark 49-F Turbopump. The CPAC pump model configuration, models a single stage, and is presented in Figure 6.11. The CPAC Program output is included in table 6.10, along with a graph of the various speed performance. As mentioned, this case considers only 1 stage of the AETB. The actual pump consists of 2 such stages on a single shaft. Unfortunately very little test data was available for comparison.

```
CPAC                                                  AETB Model

                     PUMP MODEL CONFIGURATION

ELEMENT              ELEMENT                 INLET        DISC
NUMBER                TYPE                    NODE        NODE
   1        INDUCER                            1           2
   2        IMPELLER                           2           3
   3        VANLESS DIFFUSER                   3           4
   4        1-DISC. VOLUTE                     4           5
   5        LEAKAGE w/ FS FWR RS               3           2
```

Figure 6.11. AETB CPAC model configuration.

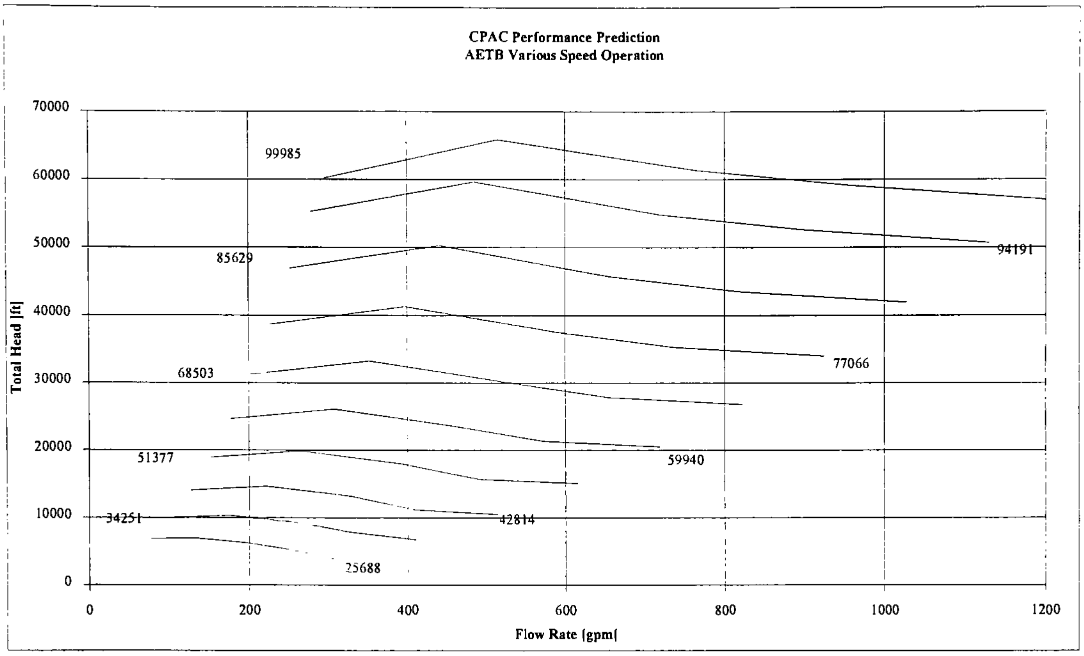

Figure 6.12. AETB total head vs flow rate (predicted).

Table 6.10. AETB CPAC predicted performance - various speeds.

CPAC AETB Model

OVERALL PUMP PERFORMANCE
IMPELLER SPEED[RPM] = 99985

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
183.89	1.80	0.0285	0.3878	1.0189	0.3806	47521.5	1409.8	38.7
294.18	2.88	0.0456	0.4963	0.8910	0.5570	60151.5	1733.6	38.7
404.57	3.96	0.0628	0.5361	0.8512	0.6298	64754.2	1784.4	38.7
514.96	5.04	0.0799	0.5461	0.8262	0.6609	65875.9	1700.6	38.7
624.95	6.11	0.0969	0.5379	0.8023	0.6705	64874.1	1524.4	38.7
764.94	7.48	0.1187	0.5089	0.7727	0.6587	61405.8	1192.5	38.7
845.93	8.28	0.1312	0.4846	0.7559	0.6411	59867.8	994.0	38.7
955.93	9.35	0.1483	0.4444	0.7334	0.6060	59164.1	742.3	38.7
1066.92	10.44	0.1655	0.3968	0.7112	0.5580	58267.3	454.0	38.7
1199.91	11.74	0.1861	0.3311	0.6850	0.4833	57022.2	65.8	38.7

OVERALL PUMP PERFORMANCE
IMPELLER SPEED[RPM] 59940

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
110.24	1.08	0.0285	0.3878	1.0189	0.3806	20342.7	606.2	38.7
176.36	1.73	0.0456	0.4963	0.8910	0.5570	24654.8	715.7	38.7
242.53	2.37	0.0628	0.5361	0.8512	0.6298	26035.9	725.6	38.7
308.71	3.02	0.0799	0.5461	0.8262	0.6609	26120.0	685.7	38.7
374.65	3.67	0.0969	0.5379	0.8023	0.6705	25396.3	611.3	38.7
458.57	4.49	0.1187	0.5089	0.7727	0.6587	23621.2	475.9	38.7
507.13	4.96	0.1312	0.4846	0.7559	0.6411	22240.9	379.4	38.7
573.07	5.61	0.1483	0.4444	0.7334	0.6060	21354.1	269.5	38.7
639.61	6.26	0.1655	0.3968	0.7112	0.5580	21003.4	165.1	38.7
719.33	7.04	0.1861	0.3311	0.6850	0.4833	20555.9	25.5	38.7

OVERALL PUMP PERFORMANCE
IMPELLER SPEED[RPM] 42814

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
78.74	0.77	0.0285	0.3878	1.0189	0.3806	11903.4	355.8	38.7
125.97	1.23	0.0456	0.4963	0.8910	0.5570	14052.7	410.1	38.7
173.24	1.70	0.0628	0.5361	0.8512	0.6298	14696.4	413.3	38.7
220.51	2.16	0.0799	0.5461	0.8262	0.6609	14668.1	390.8	38.7
267.61	2.62	0.0969	0.5379	0.8023	0.6705	14217.8	350.3	38.7
327.55	3.20	0.1187	0.5089	0.7727	0.6587	13194.2	277.7	38.7
362.23	3.54	0.1312	0.4846	0.7559	0.6411	12414.2	226.1	38.7
409.33	4.01	0.1483	0.4444	0.7334	0.6060	11172.3	146.0	38.7
456.86	4.47	0.1655	0.3968	0.7112	0.5580	10729.9	84.7	38.7
513.81	5.03	0.1861	0.3311	0.6850	0.4833	10501.5	13.5	38.7

7. Recommendations and Conclusions

7-1.0 Conclusions

It has been shown that the CPAC code is a user-friendly menu driven program that predicts turbopump performance based on the operating conditions, fluid properties, and the pump geometrics. The performance prediction of the CPAC code is generally acceptable, as a one-dimensional prediction of the average fluid flow conditions and the pump's performance output.

7-2.0 Recommendations

The future use of the CPAC code is dependent on several factors. Two of the factors have been addressed by the work of this thesis; the rewrite to a user-friendly, menu driven environment, and some verifications with respect to the programs predictive performance capabilities of cryogenic centrifugal turbopump applications. The following recommendations for the CPAC program will further extend the programs use:

1. The head drop at shut-off flow conditions that is predicted by CPAC is explained by the fact that the predicted losses increase as the flow rate approaches zero. The magnitude of the loss increase needs to be addressed. Currently there is no provision for calculating losses at the shut-off condition. Some literature searches in this area may lead to additional predictive enhancements which can be incorporated into the CPAC program.

2. The program could be ported to a PC version, preferably a Microsoft windows version, which has become a very popular desktop PC operating environment. This would ensure a wider usage base which would eventually lead to further expansion in the programs capability.

3. The CPAC code's predictive performance should be tested on various other types of pumps, (other than cryogenic centrifugal turbopumps), so that possible enhancements could be made to the code to make it more of a general purpose centrifugal pump analysis code.

4. Further theoretical and empirical enhancements should be incorporated into the code as they are made available, this again extends the capabilities and user base.

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APPENDIX A

CPAC PROGRAM TECHNICAL INFORMATION

Program Structure

The CPAC code is written in FORTRAN-77, in a User-friendly treed-menu format. The following pages attempt to explain the data storage and retrieval array system used in the program.

It is necessary to point out that with this "global" array assignment scheme for data storage, the graphics package addition can proceed, since any input, or calculated value can easily be located an exported to a graphics program for screen or printer output.

Data Management

Array Name	Dimension	Array Type	Description
A$XINC	(50,10,10)	Global	Incidence Losses
A$SKFR	(50,10,10)	Global	Skin Friction Loss
A$DIFLOS	(50,10,10)	Global	Diffusion Losses
A$ETOTLC	(50,10,10)	Global	Element Total Losses
A$NDFLWS	(100,6,10,10)	Global	Nodal Flow Rates
A$NODVEL	(100,4,10,10)	Global	Nodal Velocities
A$FLWANG	(100,4,10,10)	Global	Nodal Flow Angles
A$NODVAL	(100,4,10)	Global	Nodal Parameters
A$IMPVAL	(50,14,10,10)	Global	Impeller Values
A$PMPPER	(4,10,10)	Global	Nodal Pump Perf.
A$EFRFAC	(100,10,10)	Global	Friction Factors
A$ERENUM	(100,10,10)	Global	Reynolds Numbers
A$ESTAT	(50,10,10)	Global	Static Pressures
A$EDF	(50,10,10)	Global	Roughness Values
A$ELPER	(50,5,10,10)	Global	Element Perf. Param.
A$NDPER	(50,4,10,10)	Global	Nodal Perf. Param.
SPEEDIMP	(10)	Global	Impeller Speeds.
XINC	(50,10)	Local	Incidence Losses.
SKFR	(50,10)	Local	Skin Friction Loss
DIFLOS	(50,10)	Local	Diffusion Losses.
ETOTLC	(50,10)	Local	Total Losses.
NDFLWS	(100,6,10)	Local	Nodal Flow Rates.
NODVEL	(100,4,10)	Local	Nodal Velocities
FLWANG	(100,4,10)	Local	Nodal Flow Angles.
NODVAL	(100,4)	Local	Nodal Parameters
IMPVAL	(50,14,10)	Local	Impeller Values.
PMPPER	(4,10)	Local	Pump Perf. Values

Array Name	Dimension	Array Type	Description
EFRFAC	(100,10)	Local	Friciton Factors
ERENUM	(100,10)	Local	Reynolds Numbers
ESTAT	(50,10)	Local	Static Pressures
EDF	(50,10)	Local	Element Roughness
ELPER	(50,5,10)	Local	Element Perf. Param.
NDPER	(50,4,10)	Local	Nodal Perf. Param.
ELINFO	(50,4)	Global	Mod. Config. Param.
ELGEOM	(100,10)	Global	Nodal Geom. Param.
ELOPER	(100,19)	Global	Nodal Oper. Param.
FLNODE	(100,10,10)	Global	Nodal Fluid Props.
CUINLET	(50,10)	Local	Element Tang. Vel.
FLOWRATE	(10)	Global	Pump Flowrates.
SPEEDIMP	(10)	Global	Pump Rotor Speeds.

Program Matrix Layout

I. Pump elements: Type: integer

Name: ELINFO Dimension: 50 x 4
Convention: ELINFO(I,J)

J = 1 :	element number	ELMNUM
J = 2 :	element type	ETYPE
J = 3 :	element 1st node	- ENODE1
J = 4 :	element 2nd node	- ENODE2

II. Element geometry: Type: real

Name: ELGEOM Dimension: 100 x 10
Convention: ELGEOM(I,J)

I = n:	node number	-ENODE1,ENODE2
J = 1:	tip diameter	- DTIP
J = 2:	hub diameter	- DHUB
J = 3:	passage width	- SMB
J = 4:	blade angle	- BBRMS
J = 5:	number of blades	- Z
J = 6:	blade length	- BLENGT
J = 7:	normal thickness	TN
J = 8:	blockage	- BLOCK
J = 9:	solidity	- SOL
J = 10:	roughness	- EF

III. Element boundary/operatimg conditions:

Name: ELOPER Dimension: 50 x 18 Type: real
Convention: ELOPER(I,J)

I = n:	element number	ELNUM
J = 1:	head coef. for max. efficiency	PSIDES
J = 2:	impeller disch. flow coef. max. eff.	- PHI6ZO
J = 3:	front wear rimg loss coef.	- CWRF
J = 4:	rear wear ring loss coef.	- CWRR
J = 5:	% static head loss rear wear ring	- AKHWR
J = 6:	inducer Cu	- CU1
J = 7:	operatimg speed	- SPEED
J = 8:	imp. front tip clearance leak. coef.	- HEADK
J = 9:	imp. rear tip clearance leak. coef.	- HEADKR
J = 10:	imp. tip clearance torque coef.	- TORQK
J = 11:	blade loading coef.	- AX
J = 12:	blade loading coef.	BX
J = 13:	blade loading coef.	- CX
J = 14:	balance rib diameter	- DBR
J = 15:	imp. front wear ring area	- AWRF
J = 16:	imp. rear wear ring area	- AWRR
J = 17:	imp. front shroud clearance	- FSC
J = 18:	imp. rear shroud clearance	- RSC

IV. Element nodal fluid properties:

Name: FLNODE Dimension: 100 x 10 x 10 Type: real

Convention: FLNODE(I,J,K)

I = n:	node number	- NODNUM
J = n:	map point	MAP
K = 1:	fluid density	- RO
K = 2:	fluid viscosity	VISC
K = 3:	volume flow rate	- QBCFT
K = 4:	mass flow rate	- WTFLO
K = 5:	temperature	- TEMP
K = 6:	pressure	- PRES
K = 7:	specific heat capacity	- C
K = 8:	N/A	
K = 9:	N/A	
K = 10:	N/A	

Program calculated values and storage scheme

I. Element losses:

1: Incidence loss

Name: XINC Dimension: 50 x 10 Type: real
Convention: XINC(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

2: Skin friction loss

Name: SKFR Dimension: 50 x 10 Type: real
Convention: SKFR(I,J)
I = n: element number ELNUM
J = n: map point MAP

3: Diffusion loss

Name: DIFLOS Dimension: 50 x 10 Type: real
Convention: DIFLOS(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

4: Element total (cumulative) loss coefficient

Name: ETOTLC Dimension: 50 x 10 Type: real
Convention: ETOTLC(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

II. Element friction factor:

Name: EFRFAC Dimension: 50 x 10 Type: real
Convention: EFRFAC(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

III. Element Reynolds number:(moved to flnode 9 position)

Name: ERENUM Dimension: 50 x 10
Convention: ERENUM(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

IV. Element static pressures:

Name: ESTAT Dimension: 50 x 10 Type: real
Convention: ESTAT(I,J)
I = n: element number - ELNUM
J = n: map point MAP
Note: currently not implemented

V. Element value (future):

Name: EDF Dimension: 50 x 10 Type:real
Convention: EDF(I,J)
I = n: element number - ELNUM
J = n: map point - MAP

Note: currently not implemented

VI. Flow array

Name: NDFLWS Dimension: 100 x 6 x 10
Convention: NDFLWS(I,J,K)
I = n: node number - NODNUM
J = 1: flow coefficient - PHI
J = 2: weight flow - WTFLO
J = 3: flowrate (gpm) - QGPM
J = 4: flowrate (ft^3/min) - QCUBFT
J = 5: flowrate delta - QDEL
J = 6: flowrate (metric) - QMET
K = n: map point MAP

VII. Velocity array

Name: NODVEL Dimension: 100 x 4 x 10
Convention: NODVEL(I,J,K)

I = n: node number	NODNUM
J = 1: flow velocity (absolute)	- CRMS
J = 2: tangential velocity (abs)	- CURMS
J = 3: meridional velocity (abs)	- CMRMS
J = 4: not used	- FLVEL
K = n: map point	- MAP

VIII. Flow angle array

Name: FLWANG Dimension: 100 x 4 x 10
Convention: FLWANG(I,J,K)

I = n: node number	- NODNUM
J = 1: relative fluid angle	- BFRMS
J = 2: incidence angle	- ALPHA
J = 3: deviation angle	- ALINC
J = 4: relative fluid velocity	WPRRMS
K = n: map point	- MAP

IX. Nodal calculation array

Name: NODVAL Dimension: 100 x 4
Convention: NODVAL(I,J)

I = n: nodal number	NODNUM
J = 1: nodal ave. velocity	- URMS
J = 2: nodal diameter	- DRMS
J = 3: nodal area	- AREA
J = 4: nodal velocity	VELND

X. Impeller/Volute values array

Name: IMPVAL Dimension: 50 x 14 x 10
Convention: IMPVAL(I,J,K)

I = n: element number	- ELNUM
J = 1:	- QLEAK
J = 2:	- QLEAKR
J = 3:	- QLEAKF
J = 4:	- XLEAK
J = 5:	- HPDFR
J = 6:	- HPDFF
J = 7:	HPBRF
J = 8:	- HPBRR
J = 9:	BARB56
J = 10:	REC56
J = 11:	- CLEAR
J = 12:	VANLES
J = 13:	- XLENTH
J = 14:	XINGLE

XI. Performance array

Name: PMPPER Dimension: 4 x 10
Convention: PMPPER(I,J)

I = 1: power coefficient	- PWCOEF
I = 2: head coefficient	- HDCOEF
I = 3: pump efficiency	- EFFPMP
I = 4: pump head	- HEAPMP
J = n: map point	- MAP

XII. Head array

Name: ELHEAD Dimension: TBD
Convention: ELHEAD(TBD)

XIII. Pressure array

Name: ELPRES Dimension: TBD
Convention: ELPRES(TBD)

APPENDIX B

CPAC EQUATIONS

General Equations

The CPAC code performs the required calculations for each element in the following order:

1. Element area calculations
2. Element diameter (rms) calculations
3. Element velocity (rms) calculations
4. Element flow calculations
5. Element flow coefficient calculations
6. Element fluid velocity triangle (rms) calculations.

Area Calculation:

$$A = \frac{1}{2} \pi \text{ w } (D_{tip} + D_{hub})$$

Root Mean Square Diameter Calculation:

$$D_{rms} = \sqrt{D_{tip}^2 + D^2{}_{hub}) / 2}$$

Root Mean Square Velocity Calculation:

$$U_{rms} = \frac{D_{rms}\, N}{229.0}$$

Weight Flow Calculation:

$$WT = \frac{Q\, \rho}{448.765}$$

Flow Rate Calculation:

$$Q_{cbft} = \frac{WT}{\rho}$$

Flow Coefficient Calculation:

$$\varphi = \frac{144\ Q_{cbft}}{V_{tip}\ A_{flow}}$$

Where:

$$A_{flow} = A\,B \quad \frac{Z\ T_n\ w}{\sin(\beta_{rms})}$$

Velocity Triangle Calculations

Absolute Fluid Meridional Velocity Calculation

$$C_{m\ rms} = \varphi V_{tip}$$

Substituting φ

$$C_{m\ rms} = \frac{144\ Q_{cbft}}{A_{flow}}$$

Fluid Tangential Velocity Component Calculation

$$C_{u_i\ rms} = \frac{C_{u\ i-1\ rms} D_{i-1\ rms}}{D_{i\ rms}}$$

Absolute Fluid Velocity

$$C_{rms} = \frac{C_{m\ rms}}{\sin(\alpha)}$$

Loss Equations

Incidence Loss Calculations

$$\phi_{inc} = \frac{K_{inc}}{2\ g} \frac{S_1^{\,2}}{V_{tip}}$$

where

$$\frac{S_1}{V_{tip}} = \frac{C_{m\ rms}}{V_{tip}} \left| \cot \beta_{b1} \quad \cot \beta_{f1} \right|$$

with

$$K_{inc} = 0 \quad \text{for} \quad \left| \beta_{b1} \quad \beta_{f1} \right| \leq 2$$

$$K_{inc} = 0.3 \quad \text{for} \quad \left| \beta_{b1} - \beta_{f1} \right| > 2$$

In these equations the subscript 1 denotes the inlet to the element.

Diffusion Loss Calculations

$$D = 1 \quad \frac{W_2}{W_1} + \frac{W_1 - W_2}{2\ \sigma W_1}$$

The diffusion loss coefficient then is calculated empirically by

$$\phi_{dif} = K_{dif}\, D^N$$

The K and N values are element dependent and are listed in the following table.

Element	K	N
Inducer	0.05	2
Stator	0.03	3
Impeller	0.03	3
Diffuser	0.03	3
Volute	0.02	2
Downcomer	0.03	3

Skin Friction Loss Calculations

$$\phi_{skf} = \frac{f}{4}\,\frac{L}{D_h}\left[\frac{W_1^2}{V_{tip}^2} + \frac{W_2^2}{V_{tip}^2}\right]$$

The friction coefficient is then a function of the Reynolds number and roughness as noted above,

$$f = F(Re, \frac{e}{D_h})$$

where

$$Re = \left[\frac{W_1^2}{V_{tip}^2} + \frac{W_2^2}{V_{tip}^2}\right]\frac{D_h\,V_{tip}}{2\,\upsilon}$$

where

The hydraulic diameter, D_h, is given by

$$D_h = \frac{4}{2}\left[\frac{A_1}{P_1} + \frac{A_2}{P_2}\right]$$

and

$$A_i = \left[\frac{\pi}{Z_i}\,D_{i\,rms}\,\sin\beta_{bi}\,(B_i - Tn_i)\right](D_{tipi} - D_{hubi})$$

$$P_i = \left[2\,(D_{tipi} - D_{hubi}) + \frac{\pi}{Z_i}\,(D_{tipi} + D_{hubi})\,\sin\beta_{bi} \quad 2Tn_i\right]$$

$i = 1,2$

Volute Momentum Loss Calculation

The scroll momentum loss is determined from the following equations:

$$\phi_{scm} = K_{scm}\left[\frac{Cu_{i\,rms}}{V_{tip}}\right]^2 \left|\frac{A_{throat} - A_{scm}}{A_{throat}}\right|^2$$

where A_{scm} is the area determined from D_{scm} given below, and K_{scm} = 0.5.

$$D_{scm} = 2\sqrt{D_{throat}\, w_i \tan\alpha_i} \qquad i = \text{inlet}$$

Performance Equations

<u>Total Element Loss</u>

$$\text{Total Loss} = \sum \text{All Element Losse}$$

<u>Element Euler Head Coefficient</u>

$$Head_{Euler} = \frac{U_{rms2}Cu_2 \quad U_{rms1}Cu_1}{V_{tip}^2}$$

<u>Element Actual Head Coefficient</u>

$$Head_{Actual} = Head_{Euler} \quad \text{Total Losses}$$

<u>Element Efficiency</u>

$$e_{Element} = \frac{Head_{Actual}}{Head_{Euler}}$$

<u>Element Head Rise</u>

$$\text{Head Rise} = \frac{Head_{Actual}\, V_{tip}^2}{g}$$

Element Equations

The following pages describe the sequence of equations for the inducer, stator, impeller, vaned diffuser, diffuser, exit diffuser, volute, turning channel, downcomer, and, return passage pump elements. Where the velocity component equations are the same as those listed previously, the equations are not repeated. However, where the velocity component calculation is dependent on the element, the equation is given. Such is the case for the absolute fluid tangential velocity component, C_u which in many instances is unique to the element. Also any differences in the loss calculations for that element that are not covered in the previous equations are presented. A few items of significance are the impeller iteration scheme, as well as all the impeller mechanical loss equations. These equations are covered in detail under the impeller type element.

As noted earlier, the element's dependent variables such as the absolute fluid tangential velocity components, which require the previous elements parameters, are denoted with a subscript of i-1.

Inducer Element Calculations

Whenever an inducer type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Inducer Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \text{input value}$$

Fluid Flow Angle

$$\beta_{\text{fluid}\,1} = \arctan \frac{Cm_1}{U_{rms1}}$$

Absolute Fluid Velocity

$$C_{rms1} = \sqrt{Cu_1^2 + Cm_1^2}$$

Inducer Discharge:

Fluid Flow Angle

$$\beta_{\text{fluid}\,2} = \beta_{b2} \quad \frac{0.26\,[\beta_{b2} \quad \beta_{b1}]}{\sqrt{\alpha_2}}$$

Fluid Tangential Velocity Component

$$Cu_2 = U_{rms2} \quad \frac{Cm_2}{\tan\beta_{\text{fluid}\,2}}$$

Fluid Flow Angle

$$\alpha_2 = \arctan\frac{Cm_2}{Cu_2}$$

Absolute Fluid Velocity

$$C_{rms2} = \frac{Cm_2}{\sin\alpha_2}$$

Once these parameters have been calculated, the element losses are evaluated. These losses include an incidence loss, a skin friction loss, and a diffusion loss, and were presented earlier. Once these losses have been computed the overall inducer performance can be evaluated.

Stator Element Calculations

Whenever a stator type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Stator Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \frac{Cu_{i-1}\, D_{rms\, i-1}}{D_{rms1}}$$

Fluid Flow Angles

$$\alpha_1 = \arctan \frac{Cm_1}{Cu_1}$$

$$\beta_{fluid1} = \alpha_1$$

Absolute Fluid Velocity

$$C_{rms1} = \frac{Cm_1}{\sin \alpha_1}$$

Stator Discharge:

Fluid Flow Angles

$$\alpha_2 = \beta_{b2} - \frac{0.26[\beta_{b2} \quad \beta_{b1}]}{\sqrt{\alpha_2}}$$

$$\beta_{fluid2} = \alpha_2$$

Fluid Tangential Velocity Component

$$Cu_2 = \frac{Cm_2}{\tan \alpha_2}$$

Absolute Fluid Velocity

$$C_{rms2} = \frac{Cm_2}{\sin \alpha_2}$$

Once these parameters have been calculated, the element losses are evaluated. These losses include an incidence loss, a skin friction loss, and a diffusion loss presented above. These are all of the major equations considered in an stator type element loss evaluation.

Impeller Element Calculations

Whenever an Impeller type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These equations, however, are calculated in an iterative process, to account for the impeller leakage and the associated mechanical losses of the impeller. The following equations attempt to convey this iterative process:

Begin Iteration

Impeller Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \frac{Cu_{i-1}\, D_{rms\, i-1}}{D_{rms1}}$$

Fluid Flow Angles

$$\alpha_1 = \arctan\frac{Cm_1}{Cu_1}$$

Absolute Fluid Velocity

$$C_{rms1} = \frac{Cm_1}{\sin \alpha_1}$$

Impeller Discharge:

Several modifications are necessary in order to calculate the correct parameters for the impeller discharge, they are as follows:

$$\Delta = \frac{D_{tip1}}{D_{rms2}}$$

$$Z_2 = \frac{0.84 Z_2}{1 - 0.25\Delta}$$

$$XM = 1.0 + \frac{[1.37 + 0.23 \sin \beta_{b2}]\,[\varphi_2 + 0.05]^{0.6}}{Z_2\,(0.5)\,(1.1)\,(0.2)^{0.6}\,[1 - 0.12\Delta]}$$

Once these parameters have been calculated, the element losses are evaluated. These losses include an incidence loss, a skin friction loss, a diffusion loss, and a recirculation loss. The subroutine then goes on to calculate the mechanical losses associated with this particular type of impeller configuration.

These losses are the horsepower losses due to disc friction, and the leakage flow rate through the impeller which contributes to the incidence, skin friction and diffusion losses. These are modeled with leakage elements. These losses are calculated from the following equations:

The horsepower looses are of the form presented in Stepanoff, Centrifugal and Axial Flow Pumps, pp. 190-193.

$$Hp_d = K\, D^2 \rho\, U_{rms}^3$$

where

K = correction coefficient
D = impeller diameter
ρ = fluid density
U = impeller peripheral velocity

In CPAC,

$$U_{rms} = V_{tip}$$

$$D = \frac{\left[D_{rms2}^5 - D_{rms1}^5\right]}{D_{rms2}^3}$$

where

$$K = \frac{[9\rho]\,[0.5]\,[24]\,\left[12^5\right]}{550\ g}$$

The leakage losses are of the following form:

$$Q_{leakage} = C_{wr}\, A_{wr} \sqrt{2\ g\ H_{wr}}$$

where

A_{wr} = Leakage flow area
C_{wr} = Wear ring loss coefficient
H_{wr} = Head drop across wear ring.

Note: C_{wr}, and A_{wr} change depending on the impeller type.

Tip Clearance Leakage Losses:

The determination of the impeller tip clearance leakage losses involves the calculation of the torque ratio for the blade loading with impeller tip clearance to that of zero tip clearance. This method is based on a tip clearance study by Rocketdyne which utilizes the blade loading distribution as a function of radius. The blade loading distribution is modeled as a polynomial whose coefficients are input parameters.

Blade Loading Function: $\Delta P = A + Br + Cr^2$

where ΔP = Pressure [psid]
A,B,C = Loading Coefficients [empirically determined]
r = radius [inch]

Unfortunately the loading coefficients are only known for one specific pump, the J2 Oxidizer Pump. Inorder to extend the blade loading coefficients for this pump to other pump configurations, one may chose to scale the coefficients by a factor. One factor may be the ratio of the head coefficient at maximum efficieny to the impeller discharge tip radius. The J2 ratio is 0.088. Thus if one computes the head coefficient at maximum efficiency to the impeller discharge radius for the pump of interest, and divides this number by the J2 radius, one obtains the scaling factor for the blade loading coefficients. Thus each blade loading coefficient, (A, B, and C), would be scaled by the scaling factor.

Once these losses have been computed, the subroutine modifies the flow rates, and other flow rate dependent parameters, due to the losses and leakages of the impeller. These modifications are as follows:

Flow Rate Modification

$$Q_{cbft} = Q_{cbft} + Q_{leakage\ rear} + Q_{leakage\ front}$$

Flow Coefficient Calculation

$$\varphi = \frac{144\ Q_{cbft}}{V_{tip}\ A_{flow}}$$

where

$$A_{flow} = A\ B \quad \frac{Z\ Tn\ w}{\sin \beta_{rms}}$$

Fluid Meridional Velocity Component

$$Cm = \frac{144\ Q_{cbft}}{A_{flow}}$$

Relative Velocity

$$W = \frac{Cm}{\sin \beta}$$

Deviation Angle

$$\text{Deviation Angle}_1 = \beta_1 \quad \beta_{fluid1}$$

Recirculation Loss Calculations

The recirculation loss is calculated as follows:

"An empirical equation has been developed based on test data that gives the flow coefficient of a pump at the maximum efficiency point and is a function of the **head coefficient** at the maximum efficiency φ_{des} and **blade angle** at discharge of impeller, β_{b2} and minimum blade number for maximum efficiency Z_2. This equation is:

$$\phi_{2des} = \frac{K \, \varphi_{des} \sin \beta_{b2}}{Z_2}$$

where K = 7.03 Empirically.

The recirculation loss is considered to be zero at the maximum efficiency point. At zero flow, the required pump horsepower due to recirculation is a constant G times the design pump power required.

$$\Delta P_{crec} = 0.0 \qquad \text{at} \qquad \phi_2 = \varphi_{2des}$$

$$\Delta P_{crec} = G \, Hp_{[\text{at max } \eta]} \qquad \text{at} \qquad \phi_2 = 0.0$$

An empirical equation is then given as:

$$\Delta P_{crec} = \frac{G \, \varphi_{des} \left[\phi_{2des} \quad \phi_2\right]^{3\eta}}{\phi_2 \, \phi_{2des}^{\;2\eta}}$$

where η defines the amount of power loss with ϕ and could possibly be correlated with impeller discharge blade angle. The value G has been found from test data at shutoff or zero flow to be in the range of 0.3 to 0.5."[5]

Once these modifications have been computed, the subroutine returns to the impeller inlet to recalculate all of the above parameters with the modified flow rate values. This iteration is performed three times, (note, the flow rates are not updated after the third iteration, so that the correct flow rates are saved for the final iteration). The value of three for the number of iterations satisfies the convergence criteria of the program. When these values have been computed, the impeller performance can be evaluated.

Impeller Theoretical Head Calculations

In order to correctly evaluate a pumps performance, the theoretical head input by the impeller needs to be calculated. This input head by the impeller is always calculated from the velocities.[3]

Theoretical Head Equation

$$H_{input} = \frac{C_{rms2}^2 \quad C_{rms1}^2}{2\ g} + \frac{V_{tip}^2 \quad U_{rms1}^2}{2\ g} + \frac{W_1^2 \quad W_2^2}{2\ g}$$

In the CPAC code, the theoretical head coefficient, is calculated:

$$\psi_{\text{theory}} = \frac{[V_{tip}Cu_2 \quad U_{rms1}Cu1]}{V_{tip}^2}$$

from which the theoretical head is calculated:

$$\text{Head}_{theory} = \frac{\psi_{\text{theory}} V_{tip}^2}{g}$$

Vaned Diffuser Element Calculations

Whenever an vaned diffuser type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Vaned Diffuser Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \frac{Cu_{i-1} D_{rms\,i-1}}{D_{rms1}}$$

Fluid Flow Angles

$$\alpha_1 = \arctan\frac{Cm_1}{Cu_1}$$

$$\beta_{fluid1} = \alpha_1$$

Absolute Fluid Velocity

$$C_{rms1} = \frac{Cm_1}{\sin\alpha_1}$$

Vaned Diffuser Discharge:

Fluid Flow Angles

$$\alpha_2 = \beta_{b2} \qquad \frac{0.26[\beta_{b2} \qquad \beta_{b1}]}{\sqrt{\alpha_2}}$$

$$\beta_{fluid2} = \alpha_2$$

Fluid Tangential Velocity Component

$$Cu_2 = \frac{Cm_2}{\tan\alpha_2}$$

Absolute Fluid Velocity

$$C_{rms2} = \frac{Cm_2}{\sin\alpha_2}$$

Once these parameters have been calculated, the element losses are evaluated. These losses include an incidence loss, a skin friction loss, and a diffusion loss.

Vaneless Diffuser Element Calculations

Whenever an vaneless diffuser type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Vaneless Diffuser Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \frac{Cu_{i-1}\ D_{rms\,i-1}}{D_{rms1}}$$

Fluid Flow Angles

$$\alpha_1 = \arctan\frac{Cm_1}{Cu_1}$$

$$\beta_{fluid1} = \alpha_1$$

Absolute Fluid Velocity

$$C_{rms1} = \frac{Cm_1}{\sin\alpha_1}$$

Vaneless Diffuser Discharge:

Fluid Tangential Velocity Component

$$Cu_2 = \frac{Cu_1\ D_{rms1}}{D_{rms2}}$$

Fluid Flow Angles

$$\beta_{fluid2} = \arctan\frac{Cm_2}{Cu_2}$$

$$\alpha_2 = \beta_{fluid2}$$

Absolute Fluid Velocity

$$C_{rms2} = \frac{Cm_2}{\sin\alpha_2}$$

Once these parameters have been calculated, the element loss is evaluated. This vaneless diffuser loss is simply a friction loss calculation and is discussed in equations 18 - 23. Once this loss has been calculated, the vaneless diffuser performance can be evaluated.

Exit Diffuser Element Calculations

Whenever an exit diffuser element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously.

The program then calculates the exit diffuser loss:

$$\phi_{\text{exit diffuser}} = \frac{0.175\left[\varphi_{\text{throat}} \quad \varphi_{\text{exit dif}}\right]^2}{2}$$

Once the exit diffuser loss is known, the element performance can be calculated.

Volute Element Calculations

Whenever an volute type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

<u>Volute Throat:</u>

Absolute Fluid Velocity

$$C_{\text{rms1}} = \frac{\dfrac{144\ Q_{\text{cbft}}}{V_{\text{tip}}}}{A_{\text{throat}}\ B_{\text{throat}}}$$

Once these parameters have been calculated, the element losses are evaluated. The volute losses consist of the scroll momentum loss, a skin friction loss, and diffusion loss, the later two were added to the program at the Rochester Institute of Technology. The equations for the diffusion loss were referenced in Stirling, [1]:

First the volute solidity is calculated:

$$\sigma_{\text{volute}} = \sqrt{1 + 2\sqrt{\frac{A_{\text{throat}}}{\pi\, D_{\text{rms1}}^{2}}}}$$

Next, the volute throat velocity is calculated:

$$V_{\text{throat}} = \frac{144\ Q_{\text{cbft}}}{A_{\text{throat}}}$$

Followed by the diffusion factor calculation:

$$D = 1 \quad \frac{V_{\text{throat}}}{C_{\text{rms1}}} + \frac{\left[C_{u1} \quad V_{\text{throat}}\right]}{2\,\sigma\, C_{\text{rms1}}}$$

The diffusion loss is the calculated:

$$\phi_{\text{diffusion}} = 0.02\ D^3$$

Turning Channel Element Calculations

Whenever a turning channel type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Turning channel Inlet:

Fluid Meridional Velocity Component

$$Cm_1 = \frac{144\ Q_{cbft}\ A_1}{448.765\ Z_1}$$

Absolute Fluid Velocity

$$C_{rms1} = Cm_1$$

Relative Fluid Velocity

$$W_1 = Cm_1$$

Turning channel discharge:

Fluid Meridional Velocity Component

$$Cm_2 = \frac{144\ Q_{cbft}\ A_2}{448.765\ Z_2}$$

Absolute Fluid Velocity

$$C_{rms2} = Cm_2$$

Relative Fluid Velocity

$$W_2 = Cm_2$$

Once these parameters have been calculated, the element loss is evaluated. This loss is a skin friction loss, and was covered previously. After the element losses are evaluated, the turning channel performance can be calculated.

Downcomer Element Calculations

Whenever a downcomer type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These are as follows:

Downcomer Inlet:

Fluid Tangential Velocity Component

$$Cu_1 = \frac{Cu_{i-1}\, D_{rms\,i-1}}{D_{rms1}}$$

Fluid Flow Angles

$$\alpha_1 = \arctan\frac{Cm_1}{Cu_1}$$

$$\beta_{fluid1} = \alpha_1$$

Absolute Fluid Velocity

$$C_{rms1} = \frac{Cm_1}{\sin\alpha_1}$$

Downcomer discharge:

Fluid Tangential Velocity Component

$$Cu_2 = \frac{Cu_1\, D_{rms1}}{D_{rms2}}$$

Fluid Flow Angles

$$\beta_{fluid2} = \arctan\frac{Cm_2}{Cu_2}$$

$$\alpha_2 = \beta_{fluid2}$$

Absolute Fluid Velocity

$$C_{rms2} = \frac{Cm_2}{\sin\alpha_2}$$

Relative Fluid Velocity

$$W_{1,2} = \frac{Cm_{1,2}}{\sin\beta_{1,2}}$$

Once these parameters have been calculated, the element losses are evaluated. These losses are a skin friction loss, and, a diffusion loss. These are the same calculations performed on a vaned diffuser, without the incidence loss calculation. The downcomer performance is then evaluated after the losses have been calculated.

Return Passage Element Calculations

Whenever a return passage type element is calculated, the subroutine calculates all of the independent element parameters, as mentioned previously. Once the subroutine has calculated these element parameters, the next calculations are the element dependent parameters. These parameters follow:

Flow Rate Calculations

The flow rates are calculated using a percentage of the flow rates which are under consideration. This percentage is given as an input value known as $Q_{\%}$.

$$Q_{ret.\ passage} = \%Q\ Q_{cbft}$$

<u>Return Passage Inlet:</u>

Fluid Meridional Velocity Component

$$Cm_1 = \frac{144\ Q_{cbft}}{448.765\ A_1}$$

Absolute Fluid Velocity

$$C_{rms1} = Cm_1$$

<u>Return Passage discharge:</u>

Fluid Meridional Velocity Component

$$Cm_2 = \frac{144\ Q_{cbft}}{448.765\ A_2}$$

Absolute Fluid Velocity

$$C_{rms2} = Cm_2$$

Once these parameters have been calculated, the element skin friction loss is evaluated. The element performance is then evaluated once the element losses are known.

Overall Pump Performance Equations

After all of the elements which comprise the pump model configuration have been evaluated, the CPAC code evaluates the pump model performance. Some of the equations are included here. Many of the equations which were added at RIT simply give the head rise in terms of pressure. The static pressures are also calculated as well as the pressure coefficients.

Head Coefficient

$$\text{Head Coef} = \frac{\text{Head}_{\text{actual}}\ g}{V_{\text{tip}}^{2}}$$

Power Coefficient

$$\text{Power Coef} = \text{Head}_{\text{theory}} \quad \sum \text{Losses}$$

Head Loss Coefficient

$$\text{Head Loss Coef} = \frac{\sum \text{Head Loss}\ V_{\text{tip}}^{2}}{g}$$

Pump Efficiency

$$E_{\text{pump}} = \frac{\text{Head Loss Coefficient}}{\text{Power Coefficient}}$$

Mark 49-F Water Tester

The Mark 49-F Water Tester is a scaled up pump used during the development of the Mark 49-F turbopump. This water test program provides test data with which the CPAC program can be evaluated. A review of the literature provided from NASA Lewis Research Center provided some of the required input geometric data as well as the operating conditions. The model consists of a single stage comprised of an **inducer, impeller, vaneless diffuser, vaned diffuser, crossover**, (consisting of a **turning channel** and **downcomer** elements), as well as a **leakage** element to account for impeller shroud and wear ring leakage effects.

CPAC mark49-wt

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET TO NODE	DISC. TO NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	VANED DIFFUSER	4	5
5	TURNING CHANNEL	5	6
6	DOWNCOMER	6	7
7	LEAKAGE w/ FS FWR	3	2

INLET FLUID PROPERTIES

	INLET (NODE # 1)
FLUID DENSITY [lb/ft^3]	62.400
FLUID VISCOSITY [ft^2/s]	0.00001000

OVERALL PUMP PERFORMANCE

IMPELLER SPEED [RPM] 6322

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
291.24	40.50	0.0361	0.3235	0.8975	0.3605	977.0	415.1	519.7
350.21	48.70	0.0419	0.3722	0.8612	0.4322	1127.1	476.5	519.7
407.67	56.69	0.0475	0.3987	0.8336	0.4782	1212.9	509.4	519.7
465.99	64.79	0.0532	0.4106	0.8098	0.5070	1257.0	523.5	519.7
524.88	72.98	0.0589	0.4109	0.7882	0.5213	1267.9	522.6	519.7
583.13	81.08	0.0646	0.4017	0.7687	0.5225	1251.6	509.2	519.7
640.66	89.08	0.0702	0.3844	0.7509	0.5120	1212.6	485.4	519.7
698.91	97.18	0.0758	0.3597	0.7339	0.4900	1152.5	451.8	519.7
757.88	105.38	0.0816	0.3277	0.7178	0.4565	1087.8	415.3	519.7
816.13	113.48	0.0872	0.2897	0.7026	0.4123	1042.6	386.8	519.7

GEOMETRY
ELEMENT #1. INDUCER

INLET TIP DIAMETER [in]	5.562
INLET HUB DIAMETER [in]	3.851
INLET PASSAGE WIDTH [in]	0.856
INLET BLADE ANGLE [deg]	12
NUMBER OF INLET BLADES	4
INLET NORMAL THICKNESS [in]	0.04
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	5.562
DISCH. HUB DIAMETER [in]	4.635
DISCH. PASSAGE WIDTH [in]	0.463
DISCH. BLADE ANGLE [deg]	26
NUMBER OF DISCH. BLADES	4
DISCH. NORMAL THICKNESS [in]	0.04
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	11.8
SURFACE ROUGHNESS [in]	0.057

GEOMETRY
ELEMENT #2: IMPELLER

INLET TIP DIAMETER [in]	6
INLET HUB DIAMETER [in]	4.68
INLET PASSAGE WIDTH [in]	0.66
INLET BLADE ANGLE [deg]	19
NUMBER OF INLET BLADES	4
INLET NORMAL THICKNESS [in]	0.03
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	11.124
DISCH. HUB DIAMETER [in]	11.124
DISCH. PASSAGE WIDTH [in]	0.353
DISCH. BLADE ANGLE [deg]	30
NUMBER OF DISCH. BLADES	8
DISCH. NORMAL THICKNESS [in]	0.09
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	9.25
SURFACE ROUGHNESS [in]	0.057

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 2: IMPELLER

MAX. EFFICIENCY HEAD COEF:				0.450	
MAX. EFF. IMPELLER DISCHARGE FLOW COEF:				0.050	
IMPELLER CLEARANCE TORQUE COEF:				0.010	
IMPELLER BLADE LOADING COEF (AA)				-6328.570	
IMPELLER BLADE LOADING COEF (BB)				3143.020	
IMPELLER BLADE LOADING COEF (CC) :				-370.000	
IMPELLER FRONT SHROUD CLEARANCE [in]				0.0000	
IMPELLER REAR SHROUD CLEARANCE [in]·				8.0000	
INLET PRESSURE [PSIA]:				0.20	
INLET BYPASS FLOW RATE [%]·				0.00	
INLET CU [ft/s].	103.60	97.35	91.26	85.08	78.83
	72.66	66.56	60.39	54.13	47.96
INLET TEMP [R]:	519.67	519.67	519.67	519.67	519.67
	519.67	519.67	519.67	519.67	519.67

GEOMETRY
ELEMENT #3: VANLESS DIFFUSER

INLET TIP DIAMETER [in]	11.124
INLET HUB DIAMETER [in]	11.124
INLET PASSAGE WIDTH [in]	0.353
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	11.98
DISCH. HUB DIAMETER [in]	11.98
DISCH. PASSAGE WIDTH [in]	0.285
DISCH. BLOCKAGE	0.95
SURFACE ROUGHNESS [in]	0.0086

GEOMETRY
ELEMENT #4: VANED DIFFUSER

INLET TIP DIAMETER [in]	11.98
INLET HUB DIAMETER [in]	11.98
INLET PASSAGE WIDTH [in]	0.285
INLET BLADE ANGLE [deg]	7.65
NUMBER OF INLET VANES	17
INLET NORMAL THICKNESS [in]	0.04
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	15.656
DISCH. HUB DIAMETER [in]	15.656
DISCH. PASSAGE WIDTH [in]	0.471
DISCH. BLADE ANGLE [deg]	38.108002
NUMBER OF DISCH. VANES	17
DISCH. NORMAL THICKNESS [in]	0.807
DISCH. BLOCKAGE	0.89
VANE LENGTH [in]	2.58
SURFACE ROUGHNESS [in]	0.0086

GEOMETRY
ELEMENT #5: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.471
DISCH. HYDRAULIC DIAMETER[in]	0.471
PASSAGE LENGTH [in]	4.859
SURFACE ROUGHNESS[in]	0.0086
NUMBER OF CHANNELS	17
BLOCKAGE	0.9

GEOMETRY
ELEMENT #6: DOWNCOMER

INLET HYDRAULIC DIAMETER[in]	0.471
DISCH. HYDRAULIC DIAMETER[in]	0.471
PASSAGE LENGTH [in]	5.562
SURFACE ROUGHNESS[in]	0.0086
NUMBER OF DOWNCOMERS	17
BLOCKAGE	0.9

FLUID VELOCITIES
INDUCER INLET
(ELEMENT # 1 NODE # 1)
IMPELLER SPEED[RPM] 6322
URMS[ft/s] = 132.06

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
291.24	40.497	0.02678	8.22	0.00	8.22	39.55
350.21	48.696	0.03220	9.89	0.00	9.89	47.56
407.67	56.686	0.03748	11.51	0.00	11.51	55.36
465.99	64.795	0.04284	13.16	0.00	13.16	63.28
524.88	72.984	0.04826	14.82	0.00	14.82	71.28
583.13	81.084	0.05361	16.46	0.00	16.46	79.19
640.66	89.083	0.05890	18.09	0.00	18.09	87.00
698.91	97.182	0.06426	19.73	0.00	19.73	94.91
757.88	105.382	0.06968	21.40	0.00	21.40	102.92
816.13	113.481	0.07503	23.04	0.00	23.04	110.83

FLUID VELOCITIES
INDUCER DISCHARGE
(ELEMENT # 1 NODE # 2)
IMPELLER SPEED[RPM] = 6322
URMS[ft/s] 141.33

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
291.24	40.497	0.04678	14.37	108.89	109.83	32.77
350.21	48.696	0.05625	17.27	102.32	103.76	39.41
407.67	56.686	0.06548	20.11	95.91	98.00	45.87
465.99	64.795	0.07484	22.98	89.42	92.32	52.43
524.88	72.984	0.08430	25.89	82.85	86.81	59.06
583.13	81.084	0.09366	28.76	76.36	81.60	65.61
640.66	89.083	0.10290	31.60	69.96	76.76	72.09
698.91	97.182	0.11226	34.47	63.47	72.22	78.64
757.88	105.382	0.12173	37.38	56.90	68.08	85.28
816.13	113.481	0.13108	40.26	50.41	64.51	91.83

FLOW ANGLES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 6322

VOLUME	MASS	INLET(NODE # 1)			DISCHARGE(NODE # 2)		
FLOW RATE [GPM]	FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
291.24	40.497	3.56	90.00	8.44	23.88	7.52	2.12
350.21	48.696	4.28	90.00	7.72	23.88	9.58	2.12
407.67	56.686	4.98	90.00	7.02	23.88	11.84	2.12
465.99	64.795	5.69	90.00	6.31	23.88	14.42	2.12
524.88	72.984	6.40	90.00	5.60	23.88	17.35	2.12
583.13	81.084	7.11	90.00	4.89	23.88	20.64	2.12
640.66	89.083	7.80	90.00	4.20	23.88	24.31	2.12
698.91	97.182	8.50	90.00	3.50	23.88	28.51	2.12
757.88	105.382	9.20	90.00	2.80	23.88	33.31	2.12
816.13	113.481	9.90	90.00	2.10	23.88	38.61	2.12

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 2 NODE # 2)
IMPELLER SPEED[RPM] = 6322
URMS[ft/s] = 148.54

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
366.13	50.910	0.03723	11.43	103.60	104.23	35.12
424.66	59.049	0.04318	13.26	97.35	98.25	40.73
481.51	66.953	0.04896	15.04	91.26	92.49	46.19
539.12	74.964	0.05482	16.84	85.08	86.73	51.71
597.25	83.047	0.06073	18.65	78.83	81.01	57.29
654.72	91.038	0.06658	20.45	72.66	75.48	62.80
711.48	98.930	0.07235	22.22	66.56	70.17	68.24
768.94	106.920	0.07819	24.01	60.39	64.98	73.76
827.11	115.009	0.08411	25.83	54.13	59.98	79.34
884.59	123.001	0.08995	27.62	47.96	55.35	84.85

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 2 NODE # 3)
IMPELLER SPEED[RPM] = 6322
URMS[ft/s] 307.10

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
366.13	50.910	0.03611	11.09	236.43	236.69	22.18
424.66	59.049	0.04188	12.86	232.26	232.62	25.72
481.51	66.953	0.04749	14.58	228.31	228.77	29.17
539.12	74.964	0.05317	16.33	224.39	224.98	32.66
597.25	83.047	0.05890	18.09	220.51	221.25	36.18
654.72	91.038	0.06457	19.83	216.76	217.67	39.66
711.48	98.930	0.07017	21.55	213.12	214.21	43.10
768.94	106.920	0.07584	23.29	209.51	210.80	46.58
827.11	115.009	0.08157	25.05	205.91	207.43	50.10
884.59	123.001	0.08724	26.79	202.42	204.19	53.58

FLOW ANGLES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 2) BETA FLUID [deg]	INLET(NODE # 2) ALPHA (RMS) [deg]	INLET(NODE # 2) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 3) BETA FLUID [deg]	DISCHARGE(NODE # 3) ALPHA (RMS) [deg]	DISCHARGE(NODE # 3) DEVIATION ANGLE [deg]
366.13	50.910	14.27	6.30	4.73	8.92	2.69	21.08
424.66	59.049	14.52	7.76	4.48	9.75	3.17	20.25
481.51	66.953	14.71	9.36	4.29	10.49	3.65	19.51
539.12	74.964	14.86	11.19	4.14	11.17	4.16	18.83
597.25	83.047	14.98	13.31	4.02	11.80	4.69	18.20
654.72	91.038	15.08	15.72	3.92	12.38	5.23	17.62
711.48	98.930	15.16	18.46	3.84	12.91	5.77	17.09
768.94	106.920	15.24	21.69	3.76	13.42	6.34	16.58
827.11	115.009	15.30	25.51	3.70	13.91	6.94	16.09
884.59	123.001	15.36	29.94	3.64	14.36	7.54	15.64

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 3 NODE # 3)
IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.02741	8.42	236.43	236.58
350.21	48.696	0.03296	10.12	232.26	232.49
407.67	56.686	0.03837	11.78	228.31	228.61
465.99	64.795	0.04385	13.47	224.39	224.79
524.88	72.984	0.04940	15.17	220.51	221.03
583.13	81.084	0.05488	16.85	216.76	217.41
640.66	89.083	0.06029	18.52	213.12	213.93
698.91	97.182	0.06577	20.20	209.51	210.48
757.88	105.382	0.07132	21.90	205.91	207.08
816.13	113.481	0.07681	23.59	202.42	203.79

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 3 NODE # 4)
IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.02986	9.17	219.54	219.73
350.21	48.696	0.03591	11.03	215.67	215.95
407.67	56.686	0.04180	12.84	211.99	212.38
465.99	64.795	0.04778	14.67	208.35	208.87
524.88	72.984	0.05382	16.53	204.76	205.42
583.13	81.084	0.05979	18.36	201.27	202.11
640.66	89.083	0.06569	20.17	197.89	198.92
698.91	97.182	0.07167	22.01	194.54	195.78
757.88	105.382	0.07771	23.87	191.20	192.68
816.13	113.481	0.08368	25.70	187.96	189.71

FLOW ANGLES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 3) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 4) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
291.24	40.497	2.04	2.04	-2.04	2.39	2.39	-2.39
350.21	48.696	2.50	2.50	-2.50	2.93	2.93	-2.93
407.67	56.686	2.95	2.95	-2.95	3.47	3.47	-3.47
465.99	64.795	3.43	3.43	-3.43	4.03	4.03	-4.03
524.88	72.984	3.94	3.94	-3.94	4.62	4.62	-4.62
583.13	81.084	4.45	4.45	-4.45	5.21	5.21	-5.21
640.66	89.083	4.97	4.97	-4.97	5.82	5.82	-5.82
698.91	97.182	5.51	5.51	-5.51	6.45	6.45	-6.45
757.88	105.382	6.07	6.07	-6.07	7.11	7.11	-7.11
816.13	113.481	6.65	6.65	-6.65	7.79	7.79	-7.79

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT # 4 NODE # 4)
IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.03484	10.70	219.54	219.80
350.21	48.696	0.04190	12.87	215.67	216.05
407.67	56.686	0.04877	14.98	211.99	212.52
465.99	64.795	0.05575	17.12	208.35	209.06
524.88	72.984	0.06279	19.28	204.76	205.66
583.13	81.084	0.06976	21.42	201.27	202.41
640.66	89.083	0.07664	23.54	197.89	199.29
698.91	97.182	0.08361	25.68	194.54	196.23
757.88	105.382	0.09067	27.84	191.20	193.22
816.13	113.481	0.09763	29.98	187.96	190.34

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT # 4 NODE # 5)
IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.02999	9.21	16.13	18.58
350.21	48.696	0.03606	11.07	19.40	22.34
407.67	56.686	0.04198	12.89	22.58	26.00
465.99	64.795	0.04798	14.74	25.81	29.72
524.88	72.984	0.05405	16.60	29.07	33.48
583.13	81.084	0.06004	18.44	32.30	37.19
640.66	89.083	0.06597	20.26	35.49	40.86
698.91	97.182	0.07197	22.10	38.71	44.58
757.88	105.382	0.07804	23.97	41.98	48.34
816.13	113.481	0.08404	25.81	45.20	52.05

FLOW ANGLES
ELEMENT # 4:VANED DIFFUSER

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 4) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 5) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
291.24	40.497	2.79	2.79	4.86	29.72	29.72	8.39
350.21	48.696	3.41	3.41	4.24	29.72	29.72	8.39
407.67	56.686	4.04	4.04	3.61	29.72	29.72	8.39
465.99	64.795	4.70	4.70	2.95	29.72	29.72	8.39
524.88	72.984	5.38	5.38	2.27	29.72	29.72	8.39
583.13	81.084	6.08	6.08	1.57	29.72	29.72	8.39
640.66	89.083	6.78	6.78	0.87	29.72	29.72	8.39
698.91	97.182	7.52	7.52	0.13	29.72	29.72	8.39
757.88	105.382	8.29	8.29	-0.64	29.72	29.72	8.39
816.13	113.481	9.06	9.06	-1.41	29.72	29.72	8.39

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 5 NODE # 5)
IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	35.06	16.13	38.59
350.21	48.696	42.16	19.40	46.40
407.67	56.686	49.07	22.58	54.02
465.99	64.795	56.09	25.81	61.74
524.88	72.984	63.18	29.07	69.55
583.13	81.084	70.19	32.30	77.27
640.66	89.083	77.12	35.49	84.89
698.91	97.182	84.13	38.71	92.61
757.88	105.382	91.23	41.98	100.42
816.13	113.481	98.24	45.20	108.14

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 5 NODE # 6)
IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.00	0.00	38.59
350.21	48.696	0.00	0.00	46.40
407.67	56.686	0.00	0.00	54.02
465.99	64.795	0.00	0.00	61.74
524.88	72.984	0.00	0.00	69.55
583.13	81.084	0.00	0.00	77.27
640.66	89.083	0.00	0.00	84.89
698.91	97.182	0.00	0.00	92.61
757.88	105.382	0.00	0.00	100.42
816.13	113.481	0.00	0.00	108.14

FLOW ANGLES
ELEMENT # 5:TURNING CHANNEL

IMPELLER SPEED[RPM] 6322

		INLET(NODE # 5)			DISCHARGE(NODE # 6)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
291.24	40.497	2.79	2.79	4.86	29.72	29.72	8.39
350.21	48.696	3.41	3.41	4.24	29.72	29.72	8.39
407.67	56.686	4.04	4.04	3.61	29.72	29.72	8.39
465.99	64.795	4.70	4.70	2.95	29.72	29.72	8.39
524.88	72.984	5.38	5.38	2.27	29.72	29.72	8.39
583.13	81.084	6.08	6.08	1.57	29.72	29.72	8.39
640.66	89.083	6.78	6.78	0.87	29.72	29.72	8.39
698.91	97.182	7.52	7.52	0.13	29.72	29.72	8.39
757.88	105.382	8.29	8.29	-0.64	29.72	29.72	8.39
816.13	113.481	9.06	9.06	-1.41	29.72	29.72	8.39

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT # 6 NODE # 6)
IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.00	0.00	35.06
350.21	48.696	0.00	0.00	42.16
407.67	56.686	0.00	0.00	49.07
465.99	64.795	0.00	0.00	56.09
524.88	72.984	0.00	0.00	63.18
583.13	81.084	0.00	0.00	70.19
640.66	89.083	0.00	0.00	77.12
698.91	97.182	0.00	0.00	84.13
757.88	105.382	0.00	0.00	91.23
816.13	113.481	0.00	0.00	98.24

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT # 6 NODE # 7)
IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
291.24	40.497	0.00	0.00	35.06
350.21	48.696	0.00	0.00	42.16
407.67	56.686	0.00	0.00	49.07
465.99	64.795	0.00	0.00	56.09
524.88	72.984	0.00	0.00	63.18
583.13	81.084	0.00	0.00	70.19
640.66	89.083	0.00	0.00	77.12
698.91	97.182	0.00	0.00	84.13
757.88	105.382	0.00	0.00	91.23
816.13	113.481	0.00	0.00	98.24

FLOW ANGLES
ELEMENT # 6:DOWNCOMER

IMPELLER SPEED[RPM] 6322

		INLET(NODE # 6)			DISCHARGE(NODE # 7)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
291.24	40.497	2.79	90.00	4.86	29.72	90.00	8.39
350.21	48.696	3.41	90.00	4.24	29.72	90.00	8.39
407.67	56.686	4.04	90.00	3.61	29.72	90.00	8.39
465.99	64.795	4.70	90.00	2.95	29.72	90.00	8.39
524.88	72.984	5.38	90.00	2.27	29.72	90.00	8.39
583.13	81.084	6.08	90.00	1.57	29.72	90.00	8.39
640.66	89.083	6.78	90.00	0.87	29.72	90.00	8.39
698.91	97.182	7.52	90.00	0.13	29.72	90.00	8.39
757.88	105.382	8.29	90.00	-0.64	29.72	90.00	8.39
816.13	113.481	9.06	90.00	-1.41	29.72	90.00	8.39

NODAL PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) TOTAL HEAD [ft]	TEMP. [R]	NPSH AVAIL. [ft]	VAPOR PRES [PSIA]	STATIC PRES [PSIA]	DISCHARGE(NODE # 2) TOTAL HEAD [ft]	TEMP. [R]	STATIC PRES [PSIA]
291.24	40.497	33.9	519.7	-33.8	0.256	14.2	402.3	519.7	93.1
350.21	48.696	33.9	519.7	-22.9	0.256	14.0	371.3	519.7	88.4
407.67	56.686	33.9	519.7	-13.2	0.256	13.8	337.6	519.7	81.6
465.99	64.795	33.9	519.7	-4.3	0.256	13.5	299.9	519.7	72.5
524.88	72.984	33.9	519.7	3.7	0.256	13.2	258.0	519.7	61.1
583.13	81.084	33.9	519.7	10.8	0.256	12.9	213.0	519.7	47.5
640.66	89.083	33.9	519.7	16.8	0.256	12.5	165.1	519.7	31.8
698.91	97.182	33.9	519.7	22.0	0.256	12.1	112.9	519.7	13.8
757.88	105.382	33.9	519.7	26.3	0.256	11.6	72.0	519.7	0.0
816.13	113.481	33.9	519.7	29.6	0.256	11.1	64.7	519.7	0.0

ELEMENT LOSSES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
291.24	40.497	213327.	0.02311	0.01098	0.00343	0.03752
350.21	48.696	256520.	0.01940	0.01587	0.00295	0.03822
407.67	56.686	298606.	0.01609	0.02151	0.00252	0.04012
465.99	64.795	341324.	0.01305	0.02810	0.00213	0.04328
524.88	72.984	384463.	0.01030	0.03565	0.00176	0.04771
583.13	81.084	427129.	0.00790	0.04400	0.00143	0.05334
640.66	89.083	469268.	0.00585	0.05311	0.00114	0.06010
698.91	97.182	511933.	0.00408	0.06321	0.00088	0.06817
757.88	105.382	555125.	0.00261	0.07433	0.00065	0.07759
816.13	113.481	597791.	0.00148	0.08619	0.00046	0.08814

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
291.24	40.50	213327.	0.1257	0.1632	0.7701	368.3	78.8	0.0
350.21	48.70	256520.	0.1151	0.1533	0.7507	337.4	74.4	0.0
407.67	56.69	298606.	0.1036	0.1437	0.7209	303.7	67.8	0.0
465.99	64.79	341324.	0.0907	0.1340	0.6771	265.9	59.0	0.0
524.88	72.98	384463.	0.0765	0.1242	0.6157	224.1	47.8	0.0
583.13	81.08	427129.	0.0611	0.1144	0.5339	179.1	34.6	0.0
640.66	89.08	469268.	0.0447	0.1048	0.4267	131.1	19.3	0.0
698.91	97.18	511933.	0.0269	0.0951	0.2833	79.0	1.7	0.0
757.88	105.38	555125.	0.0130	0.0853	0.0900	38.1	-11.6	0.0
816.13	113.48	597791.	0.0105	0.0755	-0.1668	30.7	-11.1	0.0

ELEMENT LOSSES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
366.13	50.910	165438.	0.00037	0.00582	0.00209	0.00828
424.66	59.049	191885.	0.00043	0.00784	0.00108	0.00934
481.51	66.953	217573.	0.00049	0.01008	0.00057	0.01114
539.12	74.964	243604.	0.00056	0.01263	0.00030	0.01349
597.25	83.047	269871.	0.00064	0.01550	0.00015	0.01629
654.72	91.038	295839.	0.00072	0.01863	0.00007	0.01942
711.48	98.930	321483.	0.00081	0.02200	0.00003	0.02284
768.94	106.920	347447.	0.00090	0.02569	0.00001	0.02661
827.11	115.009	373734.	0.00100	0.02973	0.00000	0.03073
884.59	123.001	399705.	0.00110	0.03400	0.00000	0.03510

ELEMENT LOSSES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
291.24	40.497	1083754.	0.00000	0.25778	0.00000	0.25778
350.21	48.696	1065037.	0.00000	0.20344	0.00000	0.20344
407.67	56.686	1047368.	0.00000	0.16620	0.00000	0.16620
465.99	64.795	1029946.	0.00000	0.13825	0.00000	0.13825
524.88	72.984	1012837.	0.00000	0.11671	0.00000	0.11671
583.13	81.084	996365.	0.00000	0.10000	0.00000	0.10000
640.66	89.083	980513.	0.00000	0.08673	0.00000	0.08673
698.91	97.182	964868.	0.00000	0.07574	0.00000	0.07574
757.88	105.382	949429.	0.00000	0.06654	0.00000	0.06654
816.13	113.481	934561.	0.00000	0.05892	0.00000	0.05892

ELEMENT LOSSES
ELEMENT # 4:VANED DIFFUSER

IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
291.24	40.497	151232.	0.05187	0.00617	0.07209	0.13013
350.21	48.696	181852.	0.03810	0.00892	0.06782	0.11483
407.67	56.686	211688.	0.02677	0.01208	0.06369	0.10254
465.99	64.795	241972.	0.01735	0.01578	0.05955	0.09268
524.88	72.984	272554.	0.00993	0.02002	0.05543	0.08538
583.13	81.084	302801.	0.00463	0.02471	0.05144	0.08078
640.66	89.083	332674.	0.00136	0.02983	0.04758	0.07877
698.91	97.182	362920.	0.00003	0.03550	0.04378	0.07931
757.88	105.382	393540.	0.00069	0.04174	0.04004	0.08246
816.13	113.481	423787.	0.00330	0.04840	0.03647	0.08817

ELEMENT LOSSES
ELEMENT # 5:TURNING CHANNEL

IMPELLER SPEED[RPM] = 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
291.24	40.497	151468.	0.00000	0.00623	0.00000	0.00623
350.21	48.696	182136.	0.00000	0.00900	0.00000	0.00900
407.67	56.686	212018.	0.00000	0.01220	0.00000	0.01220
465.99	64.795	242349.	0.00000	0.01594	0.00000	0.01594
524.88	72.984	272979.	0.00000	0.02022	0.00000	0.02022
583.13	81.084	303273.	0.00000	0.02496	0.00000	0.02496
640.66	89.083	333192.	0.00000	0.03012	0.00000	0.03012
698.91	97.182	363486.	0.00000	0.03585	0.00000	0.03585
757.88	105.382	394153.	0.00000	0.04216	0.00000	0.04216
816.13	113.481	424447.	0.00000	0.04889	0.00000	0.04889

ELEMENT LOSSES
ELEMENT # 6:DOWNCOMER

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
291.24	40.497	194526.	0.00000	0.00643	0.00000	0.00643
350.21	48.696	233912.	0.00000	0.00929	0.00000	0.00929
407.67	56.686	272289.	0.00000	0.01258	0.00000	0.01258
465.99	64.795	311242.	0.00000	0.01642	0.00000	0.01642
524.88	72.984	350579.	0.00000	0.02082	0.00000	0.02082
583.13	81.084	389485.	0.00000	0.02567	0.00000	0.02567
640.66	89.083	427910.	0.00000	0.03098	0.00000	0.03098
698.91	97.182	466815.	0.00000	0.03687	0.00000	0.03687
757.88	105.382	506200.	0.00000	0.04336	0.00000	0.04336
816.13	113.481	545106.	0.00000	0.05028	0.00000	0.05028

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 7: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			6.000		
IMP. INLET HUB DIAMETER [in]			4.680		
IMP. DISC. TIP DIAMETER [in]			11.124		
IMP. DISC. HUB DIAMETER [in]			11.124		
FRONT WEAR RING LEAKAGE COEF.			0.800		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.500		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 7:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 6322

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
366.13	50.910	0.036110	10.41264	0.00000
424.66	59.049	0.041883	10.35186	0.00000
481.51	66.953	0.047489	10.26715	0.00000
539.12	74.964	0.053171	10.16837	0.00000
597.25	83.047	0.058904	10.06198	0.00000
654.72	91.038	0.064572	9.95359	0.00000
711.48	98.930	0.070170	9.84534	0.00000
768.94	106.920	0.075837	9.73568	0.00000
827.11	115.009	0.081575	9.62538	0.00000
884.59	123.001	0.087243	9.51766	0.00000

Mark 49-F Liquid Hydrogen Turbopump

The Mark 49-F 3 stage LH2 turbopump was developed for use on the RS-44 Orbital Transfer Vehicle rocket engine. This pump is unique with respect to the use of high velocity ratio diffusing crossovers between the first and second stages. The first stage includes the **inducer** followed by an **impeller** and **vaneless diffuser**. The high velocity ratio diffusing crossover is modeled as **vaned diffuser, turning channel** and **downcomer elements**. This crossover then leads to the second stage, which consists of an **impeller** followed by a **vaneless diffuser** and the second stage crossover, (again modeled as **vaned diffuser, turning channel** and **downcomer** elements). The third stage is modeled as an **impeller** element followed by a **vaneless diffuser** and a **single discharge volute**. The configuration then shows several leakage elements, which are connected to the various impellers to account for shroud leakage effects.

This model was run to predict the performance of the Mark 49-F turbopump, the pump for which the scaled-up Mark 49 water tester was built and evaluated.

This particular model was run with variable fluid properties via a link to a thermodynamics code (Gas Plus), which calculates fluid properties throughout the pump.

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET NODE	DISC. NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	VANED DIFFUSER	4	5
5	TURNING CHANNEL	5	6
6	DOWNCOMER	6	31
7	TURNING CHANNEL	31	7
8	IMPELLER	7	8
9	VANLESS DIFFUSER	8	9
10	VANED DIFFUSER	9	10
11	TURNING CHANNEL	10	11
12	DOWNCOMER	11	40
13	TURNING CHANNEL	40	12
14	IMPELLER	12	13
15	VANLESS DIFFUSER	13	14
16	VANED DIFFUSER	14	15
17	1-DISC. VOLUTE	15	16
18	LEAKAGE w/ FS FWR	3	2
19	LEAKAGE w/ FS FWR	8	7
20	LEAKAGE w/ FS FWR	13	12

FLUID PROPERTIES

FLUID DENSITY [lb/ft^3]	4.440
FLUID VISCOSITY [ft^2/s]	0.00000201

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 110000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
217.68	2.18	0.0316	1.5742	2.5576	0.6155	178830.8	5571.5	116.4
284.84	2.88	0.0413	1.8387	2.4279	0.7573	207021.0	6518.6	127.9
392.00	3.96	0.0563	1.8895	2.2966	0.8228	211644.4	6659.4	130.3
501.85	5.04	0.0713	1.8254	2.1758	0.8390	203579.5	6368.6	127.6
614.71	6.11	0.0862	1.6868	2.0592	0.8191	187148.8	5800.4	121.5
764.88	7.48	0.1050	1.4089	1.9145	0.7359	154783.8	4718.7	108.8
850.25	8.28	0.1159	1.1965	1.8323	0.6530	130272.6	3950.8	97.8
968.80	9.35	0.1304	0.8538	1.7249	0.4950	91899.0	2763.8	80.9
1110.06	10.44	0.1458	0.4200	1.6123	0.2605	47116.9	1380.2	62.7
1201.91	11.01	0.1537	0.1489	1.5519	0.0959	19138.3	545.8	51.8

GEOMETRY
ELEMENT #1: INDUCER

INLET TIP DIAMETER [in]	1.952
INLET HUB DIAMETER [in]	1.351
INLET PASSAGE WIDTH [in]	0.3
INLET BLADE ANGLE [deg]	12
NUMBER OF INLET BLADES	4
INLET NORMAL THICKNESS [in]	0.014
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	1.952
DISCH. HUB DIAMETER [in]	1.626
DISCH. PASSAGE WIDTH [in]	0.162
DISCH. BLADE ANGLE [deg]	26
NUMBER OF DISCH. BLADES	4
DISCH. NORMAL THICKNESS [in]	0.014
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	4.14
SURFACE ROUGHNESS [in]	0.0003

GEOMETRY
ELEMENTS #2,8,14: IMPELLER

INLET TIP DIAMETER [in]	1.952
INLET HUB DIAMETER [in]	1.351
INLET PASSAGE WIDTH [in]	0.3
INLET BLADE ANGLE [deg]	12
NUMBER OF INLET BLADES	4
INLET NORMAL THICKNESS [in]	0.014
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	3.9
DISCH. HUB DIAMETER [in]	3.9
DISCH. PASSAGE WIDTH [in]	0.124
DISCH. BLADE ANGLE [deg]	30
NUMBER OF DISCH. BLADES	8
DISCH. NORMAL THICKNESS [in]	0.032
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	4.14
SURFACE ROUGHNESS [in]	0.0003

BOUNDARY/OPERATING CONDITIONS
ELEMENTS #2,8,14: IMPELLER

MAX. EFFICIENCY HEAD COEF:				0.450	
MAX. EFF IMPELLER DISCHARGE FLOW COEF:				0.050	
IMPELLER CLEARANCE TORQUE COEF:				0.010	
IMPELLER BLADE LOADING COEF (AA)				-6328.570	
IMPELLER BLADE LOADING COEF (BB)				3143.020	
IMPELLER BLADE LOADING COEF (CC) :				-370.000	
IMPELLER FRONT SHROUD CLEARANCE [in]:				0.0000	
IMPELLER REAR SHROUD CLEARANCE [in]:				2.8000	
INLET PRESSURE [PSIA].				0.07	
INLET BYPASS FLOW RATE [%]				0.00	
INLET CU [ft/s]:	701.87	631.99	524.13	418.89	314.66
	182.33	105.65	2.25	-108.41	-167.48
INLET TEMP. [R]·	46.49	45.79	44.53	43.18	41.64
	39.43	38.00	36.34	36.76	37.07

GEOMETRY
ELEMENTS #3,9,15: VANLESS DIFFUSER

INLET TIP DIAMETER [in]	3.9
INLET HUB DIAMETER [in]	3.9
INLET PASSAGE WIDTH [in]	0.124
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	4.204
DISCH. HUB DIAMETER [in]	4.204
DISCH. PASSAGE WIDTH [in]	0.1
DISCH. BLOCKAGE	0.95
SURFACE ROUGHNESS [in]	0.0003

GEOMETRY
ELEMENTS #4,10,16: VANED DIFFUSER

INLET TIP DIAMETER [in]	4.204
INLET HUB DIAMETER [in]	4.204
INLET PASSAGE WIDTH [in]	0.1
INLET BLADE ANGLE [deg]	7.65
NUMBER OF INLET VANES	17
INLET NORMAL THICKNESS [in]	0.014
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	5.493
DISCH. HUB DIAMETER [in]	5.493
DISCH. PASSAGE WIDTH [in]	0.165
DISCH. BLADE ANGLE [deg]	38.108002
NUMBER OF DISCH. VANES	17
DISCH. NORMAL THICKNESS [in]	0.312
DISCH. BLOCKAGE	0.89
VANE LENGTH [in]	0.905
SURFACE ROUGHNESS [in]	0.0003

GEOMETRY
ELEMENTS #5,11: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.471
DISCH. HYDRAULIC DIAMETER[in]	0.471
PASSAGE LENGTH [in]	4.859
SURFACE ROUGHNESS[in]	0.0003
NUMBER OF CHANNELS	17
BLOCKAGE	0.9

GEOMETRY
ELEMENTS #6,12: DOWNCOMER

INLET HYDRAULIC DIAMETER[in]	0.471
DISCH. HYDRAULIC DIAMETER[in]	0.77
PASSAGE LENGTH [in]	3.2
SURFACE ROUGHNESS[in]	0.0003
NUMBER OF DOWNCOMERS	17
BLOCKAGE	0.89

GEOMETRY
ELEMENTS #7,13: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.77
DISCH. HYDRAULIC DIAMETER[in]	0.601
PASSAGE LENGTH [in]	4.859
SURFACE ROUGHNESS[in]	0.0003
NUMBER OF CHANNELS	17
BLOCKAGE	0.9

GEOMETRY
ELEMENT #17: 1-DISC. VOLUTE

THROAT DIAMETER [in]	5.54
THROAT AREA [in^2]	15.01
BLOCKAGE	0.95
SURFACE ROUGHNESS	0.0003

FLUID VELOCITIES
INDUCER INLET
(ELEMENT # 1 NODE # 1)
IMPELLER SPEED[RPM] 110000
URMS[ft/s] 806.32

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
219.96	2.176	0.02695	50.49	0.00	50.49	242.85
290.93	2.878	0.03565	66.78	0.00	66.78	321.21
400.20	3.958	0.04904	91.87	0.00	91.87	441.85
509.56	5.038	0.06244	116.97	0.00	116.97	562.59
618.65	6.114	0.07580	142.01	0.00	142.01	683.03
757.69	7.483	0.09284	173.93	0.00	173.93	836.55
838.27	8.276	0.10272	192.42	0.00	192.42	925.51
947.87	9.352	0.11615	217.58	0.00	217.58	1046.52
1058.70	10.438	0.12973	243.02	0.00	243.02	1168.88
1116.71	11.005	0.13683	256.34	0.00	256.34	1232.93

FLUID VELOCITIES
INDUCER DISCHARGE
(ELEMENT # 1 NODE # 2)
IMPELLER SPEED[RPM] = 110000
URMS[ft/s] 862.90

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
228.18	2.176	0.04893	91.67	655.85	662.22	209.11
300.14	2.878	0.06436	120.57	590.55	602.74	275.05
411.20	3.958	0.08818	165.19	489.76	516.87	376.84
519.57	5.038	0.11142	208.73	391.42	443.60	476.15
626.89	6.114	0.13444	251.85	294.03	387.14	574.50
763.15	7.483	0.16366	306.59	170.37	350.75	699.39
842.11	8.276	0.18059	338.31	98.72	352.42	771.75
948.61	9.352	0.20342	381.09	2.10	381.09	869.32
1062.55	10.438	0.22786	426.86	-101.30	-438.72	973.74
1123.39	11.005	0.24090	451.30	-156.50	-477.67	1029.49

FLOW ANGLES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) BETA FLUID [deg]	INLET(NODE # 1) ALPHA (RMS) [deg]	INLET(NODE # 1) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 2) BETA FLUID [deg]	DISCHARGE(NODE # 2) ALPHA (RMS) [deg]	DISCHARGE(NODE # 2) DEVIATION ANGLE [deg]
228.18	2.176	3.58	90.00	8.42	23.88	7.96	2.12
300.14	2.878	4.73	90.00	7.27	23.88	11.54	2.12
411.20	3.958	6.50	90.00	5.50	23.88	18.64	2.12
519.57	5.038	8.25	90.00	3.75	23.88	28.07	2.12
626.89	6.114	9.99	90.00	2.01	23.88	40.58	2.12
763.15	7.483	12.17	90.00	-0.17	23.88	60.94	2.12
842.11	8.276	13.42	90.00	-1.42	23.88	73.73	2.12
948.61	9.352	15.10	90.00	-3.10	23.88	89.68	2.12
1062.55	10.438	16.77	90.00	-4.77	23.88	-76.65	2.12
1123.39	11.005	17.64	90.00	-5.64	23.88	-70.87	2.12

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 2 NODE # 2)
IMPELLER SPEED[RPM] 110000
URMS[ft/s] 806.32

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
228.35	2.176	0.02944	55.16	701.87	704.04	265.28
300.29	2.878	0.03848	72.08	631.99	636.09	346.69
409.87	3.958	0.05254	98.42	524.13	533.29	473.38
518.62	5.038	0.06653	124.64	418.89	437.04	599.47
626.37	6.114	0.08039	150.60	314.66	348.84	724.33
763.08	7.483	0.09796	183.51	182.33	258.69	882.65
842.12	8.276	0.10812	202.54	105.65	228.44	974.16
948.38	9.352	0.12159	227.78	2.25	227.79	1095.55
1062.45	10.438	0.13597	254.72	-108.41	-276.83	1225.16
1123.38	11.005	0.14338	268.59	-167.48	-316.53	1291.87

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 2 NODE # 3)
IMPELLER SPEED[RPM] 110000
URMS[ft/s] = 1873.36

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
253.53	2.176	0.03157	59.13	1464.03	1465.23	118.27
329.04	2.878	0.04125	77.28	1420.90	1423.01	154.55
449.48	3.958	0.05633	105.52	1357.07	1361.17	211.04
569.72	5.038	0.07133	133.62	1296.90	1303.77	267.25
688.68	6.114	0.08618	161.45	1240.13	1250.60	322.91
839.45	7.483	0.10502	196.74	1171.55	1187.96	393.49
926.58	8.276	0.11591	217.14	1133.44	1154.06	434.29
1040.45	9.352	0.13035	244.20	1084.43	1111.59	488.40
1161.28	10.438	0.14578	273.09	1033.86	1069.32	546.18
1220.86	11.005	0.15371	287.96	1008.47	1048.78	575.92

FLOW ANGLES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 2) BETA FLUID [deg]	INLET(NODE # 2) ALPHA (RMS) [deg]	INLET(NODE # 2) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 3) BETA FLUID [deg]	DISCHARGE(NODE # 3) ALPHA (RMS) [deg]	DISCHARGE(NODE # 3) DEVIATION ANGLE [deg]
253.53	2.176	27.84	4.49	-15.84	8.22	2.31	21.78
329.04	2.878	22.46	6.51	-10.46	9.69	3.11	20.31
449.48	3.958	19.23	10.64	-7.23	11.55	4.45	18.45
569.72	5.038	17.83	16.57	-5.83	13.05	5.88	16.95
688.68	6.114	17.03	25.58	-5.03	14.30	7.42	15.70
839.45	7.483	16.39	45.19	-4.39	15.66	9.53	14.34
926.58	8.276	16.12	62.45	-4.12	16.36	10.85	13.64
1040.45	9.352	15.82	89.43	-3.82	17.20	12.69	12.80
1161.28	10.438	15.56	-66.95	-3.56	18.02	14.80	11.98
1220.86	11.005	15.42	-58.05	-3.42	18.41	15.94	11.59

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 3 NODE # 3)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
253.33	2.176	0.03173	59.45	1464.03	1465.24
328.87	2.878	0.04120	77.18	1420.90	1423.00
449.20	3.958	0.05627	105.42	1357.07	1361.16
569.27	5.038	0.07131	133.59	1296.90	1303.77
687.96	6.114	0.08618	161.45	1240.13	1250.60
838.04	7.483	0.10498	196.67	1171.55	1187.95
924.45	8.276	0.11580	216.94	1133.44	1154.02
1041.96	9.352	0.13052	244.52	1084.43	1111.66
1157.16	10.438	0.14496	271.56	1033.86	1068.93
1217.05	11.005	0.15246	285.61	1008.47	1048.14

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 3 NODE # 4)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
248.91	2.176	0.03398	63.66	1358.17	1359.66
323.14	2.878	0.04412	82.64	1318.15	1320.75
441.49	3.958	0.06027	112.91	1258.93	1263.99
559.87	5.038	0.07643	143.19	1203.12	1211.61
677.21	6.114	0.09245	173.20	1150.45	1163.42
825.99	7.483	0.11276	211.24	1086.83	1107.18
911.83	8.276	0.12448	233.20	1051.48	1077.03
1028.78	9.352	0.14045	263.11	1006.01	1039.85
1144.21	10.438	0.15620	292.63	959.10	1002.75
1204.30	11.005	0.16441	307.99	935.55	984.94

FLOW ANGLES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 3) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 4) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
248.91	2.176	2.33	2.33	-2.33	2.68	2.68	-2.68
323.14	2.878	3.11	3.11	-3.11	3.59	3.59	-3.59
441.49	3.958	4.44	4.44	-4.44	5.12	5.12	-5.12
559.87	5.038	5.88	5.88	-5.88	6.79	6.79	-6.79
677.21	6.114	7.42	7.42	-7.42	8.56	8.56	-8.56
825.99	7.483	9.53	9.53	-9.53	11.00	11.00	-11.00
911.83	8.276	10.84	10.84	-10.84	12.50	12.50	-12.50
1028.78	9.352	12.71	12.71	-12.71	14.66	14.66	-14.66
1144.21	10.438	14.72	14.72	-14.72	16.97	16.97	-16.97
1204.30	11.005	15.81	15.81	-15.81	18.22	18.22	-18.22

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT # 4 NODE # 4)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
248.84	2.176	0.03962	74.22	1358.17	1360.20
323.10	2.878	0.05144	96.36	1318.15	1321.68
441.45	3.958	0.07028	131.66	1258.93	1265.80
559.83	5.038	0.08913	166.97	1203.12	1214.65
677.17	6.114	0.10781	201.96	1150.45	1168.05
825.95	7.483	0.13149	246.33	1086.83	1114.40
911.79	8.276	0.14516	271.94	1051.48	1086.08
1028.75	9.352	0.16378	306.82	1006.01	1051.77
1144.18	10.438	0.18216	341.24	959.10	1018.00
1204.27	11.005	0.19172	359.16	935.55	1002.13

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT # 4 NODE # 5)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.56	2.176	0.03370	63.13	110.58	127.33
291.32	2.878	0.04471	83.76	146.72	168.94
402.02	3.958	0.06170	115.58	202.47	233.14
513.94	5.038	0.07888	147.76	258.84	298.04
626.81	6.114	0.09620	180.21	315.68	363.50
773.58	7.483	0.11872	222.41	389.60	448.61
860.07	8.276	0.13200	247.28	433.16	498.77
976.58	9.352	0.14988	280.77	491.83	566.33
1101.36	10.438	0.16903	316.65	554.68	638.70
1168.99	11.005	0.17941	336.09	588.74	677.92

FLOW ANGLES
ELEMENT # 4:VANED DIFFUSER

IMPELLER SPEED[RPM] = 110000

		INLET(NODE # 4)			DISCHARGE(NODE # 5)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
219.56	2.176	3.13	3.13	4.52	29.72	29.72	8.39
291.32	2.878	4.18	4.18	3.47	29.72	29.72	8.39
402.02	3.958	5.97	5.97	1.68	29.72	29.72	8.39
513.94	5.038	7.90	7.90	-0.25	29.72	29.72	8.39
626.81	6.114	9.96	9.96	-2.31	29.72	29.72	8.39
773.58	7.483	12.77	12.77	-5.12	29.72	29.72	8.39
860.07	8.276	14.50	14.50	-6.85	29.72	29.72	8.39
976.58	9.352	16.96	16.96	-9.31	29.72	29.72	8.39
1101.36	10.438	19.59	19.59	-11.94	29.72	29.72	8.39
1168.99	11.005	21.00	21.00	-13.35	29.72	29.72	8.39

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 5 NODE # 5)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.54	2.176	26.43	110.58	113.69
290.91	2.878	35.02	146.72	150.84
401.64	3.958	48.35	202.47	208.16
513.52	5.038	61.81	258.84	266.11
626.21	6.114	75.38	315.68	324.55
772.37	7.483	92.97	389.60	400.54
857.93	8.276	103.27	433.16	445.30
976.28	9.352	117.51	491.83	505.68
1100.58	10.438	132.48	554.68	570.28
1167.72	11.005	140.56	588.74	605.28

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 5 NODE # 6)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.54	2.176	0.00	0.00	113.69
290.90	2.878	0.00	0.00	150.84
401.64	3.958	0.00	0.00	208.16
513.53	5.038	0.00	0.00	266.12
626.24	6.114	0.00	0.00	324.57
772.47	7.483	0.00	0.00	400.58
857.91	8.276	0.00	0.00	445.29
976.23	9.352	0.00	0.00	505.65
1100.68	10.438	0.00	0.00	570.32
1168.04	11.005	0.00	0.00	605.43

FLOW ANGLES
ELEMENT # 5:TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 5) BETA FLUID [deg]	INLET(NODE # 5) ALPHA (RMS) [deg]	INLET(NODE # 5) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 6) BETA FLUID [deg]	DISCHARGE(NODE # 6) ALPHA (RMS) [deg]	DISCHARGE(NODE # 6) DEVIATION ANGLE [deg]
219.54	2.176	3.13	3.13	4.52	29.72	29.72	8.39
290.90	2.878	4.18	4.18	3.47	29.72	29.72	8.39
401.64	3.958	5.97	5.97	1.68	29.72	29.72	8.39
513.53	5.038	7.90	7.90	-0.25	29.72	29.72	8.39
626.24	6.114	9.96	9.96	-2.31	29.72	29.72	8.39
772.47	7.483	12.77	12.77	-5.12	29.72	29.72	8.39
857.91	8.276	14.50	14.50	-6.85	29.72	29.72	8.39
976.23	9.352	16.96	16.96	-9.31	29.72	29.72	8.39
1100.68	10.438	19.59	19.59	-11.94	29.72	29.72	8.39
1168.04	11.005	21.00	21.00	-13.35	29.72	29.72	8.39

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT # 6 NODE # 6)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.54	2.176	0.00	0.00	26.72
290.90	2.878	0.00	0.00	35.41
401.64	3.958	0.00	0.00	48.89
513.53	5.038	0.00	0.00	62.51
626.24	6.114	0.00	0.00	76.23
772.47	7.483	0.00	0.00	94.03
857.91	8.276	0.00	0.00	104.43
976.22	9.352	0.00	0.00	118.83
1100.65	10.438	0.00	0.00	133.98
1168.01	11.005	0.00	0.00	142.17

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT # 6 NODE #31)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.53	2.176	0.00	0.00	10.00
290.89	2.878	0.00	0.00	13.25
401.60	3.958	0.00	0.00	18.29
513.44	5.038	0.00	0.00	23.38
626.07	6.114	0.00	0.00	28.51
772.12	7.483	0.00	0.00	35.17
857.41	8.276	0.00	0.00	39.05
975.41	9.352	0.00	0.00	44.42
1099.36	10.438	0.00	0.00	50.07
1166.35	11.005	0.00	0.00	53.12

FLOW ANGLES
ELEMENT # 6:DOWNCOMER

IMPELLER SPEED[RPM] = 110000

VOLUME	MASS	INLET(NODE # 6)			DISCHARGE(NODE #31)		
FLOW RATE [GPM]	FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
219.53	2.176	3.13	90.00	4.52	29.72	90.00	8.39
290.89	2.878	4.18	90.00	3.47	29.72	90.00	8.39
401.60	3.958	5.97	90.00	1.68	29.72	90.00	8.39
513.44	5.038	7.90	90.00	-0.25	29.72	90.00	8.39
626.07	6.114	9.96	90.00	-2.31	29.72	90.00	8.39
772.12	7.483	12.77	90.00	-5.12	29.72	90.00	8.39
857.41	8.276	14.50	90.00	-6.85	29.72	90.00	8.39
975.41	9.352	16.96	90.00	-9.31	29.72	90.00	8.39
1099.36	10.438	19.59	90.00	-11.94	29.72	90.00	8.39
1166.35	11.005	21.00	90.00	-13.35	29.72	90.00	8.39

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 7 NODE #31)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.53	2.176	9.89	0.00	9.89
290.89	2.878	13.10	0.00	13.10
401.60	3.958	18.09	0.00	18.09
513.44	5.038	23.12	0.00	23.12
626.07	6.114	28.20	0.00	28.20
772.12	7.483	34.77	0.00	34.77
857.41	8.276	38.62	0.00	38.62
975.41	9.352	43.93	0.00	43.93
1099.36	10.438	49.51	0.00	49.51
1166.35	11.005	52.53	0.00	52.53

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 7 NODE # 7)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.53	2.176	0.00	0.00	16.23
290.89	2.878	0.00	0.00	21.51
401.61	3.958	0.00	0.00	29.69
513.47	5.038	0.00	0.00	37.96
626.11	6.114	0.00	0.00	46.29
772.21	7.483	0.00	0.00	57.09
857.54	8.276	0.00	0.00	63.40
975.62	9.352	0.00	0.00	72.12
1099.71	10.438	0.00	0.00	81.30
1166.80	11.005	0.00	0.00	86.26

FLOW ANGLES
ELEMENT # 7:TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

		INLET(NODE #31)			DISCHARGE(NODE # 7)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
219.53	2.176	3.13	90.00	4.52	29.72	90.00	8.39
290.89	2.878	4.18	90.00	3.47	29.72	90.00	8.39
401.61	3.958	5.97	90.00	1.68	29.72	90.00	8.39
513.47	5.038	7.90	90.00	-0.25	29.72	90.00	8.39
626.11	6.114	9.96	90.00	-2.31	29.72	90.00	8.39
772.21	7.483	12.77	90.00	-5.12	29.72	90.00	8.39
857.54	8.276	14.50	90.00	-6.85	29.72	90.00	8.39
975.62	9.352	16.96	90.00	-9.31	29.72	90.00	8.39
1099.71	10.438	19.59	90.00	-11.94	29.72	90.00	8.39
1166.80	11.005	21.00	90.00	-13.35	29.72	90.00	8.39

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 8 NODE # 7)
IMPELLER SPEED[RPM] 110000
URMS[ft/s] 806.32

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
219.53	2.176	0.02835	53.10	0.00	53.10	255.41
290.89	2.878	0.03716	69.61	0.00	69.61	334.81
401.61	3.958	0.05108	95.69	0.00	95.69	460.23
513.47	5.038	0.06516	122.07	0.00	122.07	587.13
626.11	6.114	0.07937	148.69	0.00	148.69	715.16
772.21	7.483	0.09786	183.32	0.00	183.32	881.74
857.54	8.276	0.10878	203.79	0.00	203.79	980.18
975.62	9.352	0.12314	230.69	0.00	230.69	1109.54
1099.71	10.438	0.13857	259.59	0.00	259.59	1248.57
1166.80	11.005	0.14687	275.14	0.00	275.14	1323.33

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 8 NODE # 8)
IMPELLER SPEED[RPM] = 110000
URMS[ft/s] 1873.36

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
244.48	2.176	0.03039	56.93	1469.39	1470.50	113.86
316.70	2.878	0.03984	74.63	1427.08	1429.04	149.26
433.28	3.958	0.05476	102.59	1363.52	1367.38	205.17
551.47	5.038	0.06986	130.87	1302.66	1309.22	261.75
670.93	6.114	0.08509	159.41	1244.21	1254.38	318.82
826.90	7.483	0.10491	196.54	1171.94	1188.31	393.08
920.25	8.276	0.11663	218.49	1130.97	1151.89	436.97
1036.10	9.352	0.13202	247.32	1078.89	1106.88	494.64
1163.87	10.438	0.14856	278.31	1024.90	1062.02	556.62
1232.17	11.005	0.15746	294.97	996.64	1039.38	589.95

FLOW ANGLES
ELEMENT # 8:IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 7) BETA FLUID [deg]	INLET(NODE # 7) ALPHA (RMS) [deg]	INLET(NODE # 7) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 8) BETA FLUID [deg]	DISCHARGE(NODE # 8) ALPHA (RMS) [deg]	DISCHARGE(NODE # 8) DEVIATION ANGLE [deg]
244.48	2.176	3.77	90.00	8.23	8.02	2.22	21.98
316.70	2.878	4.93	90.00	7.07	9.49	2.99	20.51
433.28	3.958	6.77	90.00	5.23	11.38	4.30	18.62
551.47	5.038	8.61	90.00	3.39	12.92	5.74	17.08
670.93	6.114	10.45	90.00	1.55	14.22	7.30	15.78
826.90	7.483	12.81	90.00	-0.81	15.65	9.52	14.35
920.25	8.276	14.18	90.00	-2.18	16.40	10.93	13.60
1036.10	9.352	15.97	90.00	-3.97	17.29	12.91	12.71
1163.87	10.438	17.85	90.00	-5.85	18.16	15.19	11.84
1232.17	11.005	18.84	90.00	-6.84	18.60	16.49	11.40

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 9 NODE # 8)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
244.94	2.176	0.03068	57.48	1469.39	1470.52
316.97	2.878	0.03971	74.38	1427.08	1429.03
433.58	3.958	0.05431	101.75	1363.52	1367.32
551.78	5.038	0.06912	129.49	1302.66	1309.08
671.24	6.114	0.08409	157.52	1244.21	1254.15
827.17	7.483	0.10362	194.12	1171.94	1187.91
920.65	8.276	0.11533	216.05	1130.97	1151.43
1037.32	9.352	0.12994	243.43	1078.89	1106.02
1166.11	10.438	0.14608	273.66	1024.90	1060.81
1235.49	11.005	0.15477	289.94	996.64	1037.96

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 9 NODE # 9)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
241.43	2.176	0.03296	61.74	1363.14	1364.54
312.96	2.878	0.04272	80.04	1323.89	1326.31
428.25	3.958	0.05846	109.52	1264.92	1269.66
545.18	5.038	0.07443	139.43	1208.46	1216.48
663.42	6.114	0.09057	169.67	1154.24	1166.65
817.74	7.483	0.11164	209.13	1087.19	1107.13
910.18	8.276	0.12425	232.77	1049.19	1074.71
1026.25	9.352	0.14010	262.46	1000.87	1034.72
1153.86	10.438	0.15752	295.09	950.79	995.53
1222.55	11.005	0.16690	312.66	924.57	976.01

FLOW ANGLES
ELEMENT # 9:VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 8) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 9) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
241.43	2.176	2.24	2.24	-2.24	2.59	2.59	-2.59
312.96	2.878	2.98	2.98	-2.98	3.46	3.46	-3.46
428.25	3.958	4.27	4.27	-4.27	4.95	4.95	-4.95
545.18	5.038	5.68	5.68	-5.68	6.58	6.58	-6.58
663.42	6.114	7.22	7.22	-7.22	8.36	8.36	-8.36
817.74	7.483	9.40	9.40	-9.40	10.89	10.89	-10.89
910.18	8.276	10.81	10.81	-10.81	12.51	12.51	-12.51
1026.25	9.352	12.71	12.71	-12.71	14.69	14.69	-14.69
1153.86	10.438	14.95	14.95	-14.95	17.24	17.24	-17.24
1222.55	11.005	16.22	16.22	-16.22	18.68	18.68	-18.68

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT #10 NODE # 9)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
241.38	2.176	0.03843	71.99	1363.14	1365.04
312.93	2.878	0.04982	93.33	1323.89	1327.18
428.23	3.958	0.06818	127.72	1264.92	1271.36
545.17	5.038	0.08679	162.59	1208.46	1219.35
663.41	6.114	0.10562	197.86	1154.24	1171.08
817.73	7.483	0.13018	243.88	1087.19	1114.21
910.16	8.276	0.14490	271.45	1049.19	1083.74
1026.23	9.352	0.16338	306.07	1000.87	1046.63
1153.84	10.438	0.18369	344.12	950.79	1011.15
1222.53	11.005	0.19463	364.61	924.57	993.87

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT #10 NODE #10)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.47	2.176	0.03368	63.10	110.53	127.27
288.99	2.878	0.04435	83.09	145.54	167.59
398.59	3.958	0.06117	114.60	200.74	231.15
510.21	5.038	0.07830	146.69	256.95	295.88
623.82	6.114	0.09574	179.35	314.17	361.76
773.17	7.483	0.11866	222.29	389.39	448.37
863.23	8.276	0.13248	248.18	434.74	500.60
986.16	9.352	0.15135	283.53	496.66	571.89
1125.92	10.438	0.17280	323.71	567.04	652.94
1209.08	11.005	0.18556	347.62	608.92	701.16

FLOW ANGLES
ELEMENT #10: VANED DIFFUSER

IMPELLER SPEED[RPM] = 110000

		INLET(NODE # 9)			DISCHARGE(NODE #10)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
219.47	2.176	3.02	3.02	4.63	29.72	29.72	8.39
288.99	2.878	4.03	4.03	3.62	29.72	29.72	8.39
398.59	3.958	5.77	5.77	1.88	29.72	29.72	8.39
510.21	5.038	7.66	7.66	-0.01	29.72	29.72	8.39
623.82	6.114	9.73	9.73	-2.08	29.72	29.72	8.39
773.17	7.483	12.64	12.64	-4.99	29.72	29.72	8.39
863.23	8.276	14.51	14.51	-6.86	29.72	29.72	8.39
986.16	9.352	17.00	17.00	-9.35	29.72	29.72	8.39
1125.92	10.438	19.90	19.90	-12.25	29.72	29.72	8.39
1209.08	11.005	21.52	21.52	-13.87	29.72	29.72	8.39

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT #11 NODE #10)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	26.38	110.53	113.64
288.80	2.878	34.76	145.54	149.64
398.44	3.958	47.96	200.74	206.39
510.04	5.038	61.39	256.95	264.19
623.56	6.114	75.06	314.17	323.01
772.50	7.483	92.99	389.39	400.34
863.64	8.276	103.96	434.74	447.00
984.80	9.352	118.54	496.66	510.61
1122.74	10.438	135.15	567.04	582.93
1206.24	11.005	145.20	608.92	626.00

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT #11 NODE #11)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	0.00	0.00	113.63
288.81	2.878	0.00	0.00	149.64
398.45	3.958	0.00	0.00	206.40
510.06	5.038	0.00	0.00	264.19
623.58	6.114	0.00	0.00	323.02
772.45	7.483	0.00	0.00	400.31
863.94	8.276	0.00	0.00	447.12
985.40	9.352	0.00	0.00	510.86
1123.99	10.438	0.00	0.00	583.47
1209.29	11.005	0.00	0.00	627.36

FLOW ANGLES
ELEMENT #11: TURNING CHANNEL

IMPELLER SPEED[RPM] 110000

		INLET(NODE #10)			DISCHARGE(NODE #11)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
219.17	2.176	3.02	3.02	4.63	29.72	29.72	8.39
288.81	2.878	4.03	4.03	3.62	29.72	29.72	8.39
398.45	3.958	5.77	5.77	1.88	29.72	29.72	8.39
510.06	5.038	7.66	7.66	-0.01	29.72	29.72	8.39
623.58	6.114	9.73	9.73	-2.08	29.72	29.72	8.39
772.45	7.483	12.64	12.64	-4.99	29.72	29.72	8.39
863.94	8.276	14.51	14.51	-6.86	29.72	29.72	8.39
985.40	9.352	17.00	17.00	-9.35	29.72	29.72	8.39
1123.99	10.438	19.90	19.90	-12.25	29.72	29.72	8.39
1209.29	11.005	21.52	21.52	-13.87	29.72	29.72	8.39

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT #12 NODE #11)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	0.00	0.00	26.68
288.81	2.878	0.00	0.00	35.15
398.45	3.958	0.00	0.00	48.50
510.06	5.038	0.00	0.00	62.09
623.58	6.114	0.00	0.00	75.90
772.44	7.483	0.00	0.00	94.02
863.94	8.276	0.00	0.00	105.16
985.40	9.352	0.00	0.00	119.95
1123.99	10.438	0.00	0.00	136.82
1209.34	11.005	0.00	0.00	147.21

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT #12 NODE #40)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	0.00	0.00	9.98
288.79	2.878	0.00	0.00	13.15
398.42	3.958	0.00	0.00	18.15
509.99	5.038	0.00	0.00	23.23
623.44	6.114	0.00	0.00	28.39
772.15	7.483	0.00	0.00	35.17
863.49	8.276	0.00	0.00	39.33
984.63	9.352	0.00	0.00	44.85
1122.58	10.438	0.00	0.00	51.13
1207.19	11.005	0.00	0.00	54.98

FLOW ANGLES
ELEMENT #12: DOWNCOMER

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #11) BETA FLUID [deg]	INLET(NODE #11) ALPHA (RMS) [deg]	INLET(NODE #11) DEVIATION ANGLE [deg]	DISCHARGE(NODE #40) BETA FLUID [deg]	DISCHARGE(NODE #40) ALPHA (RMS) [deg]	DISCHARGE(NODE #40) DEVIATION ANGLE [deg]
219.17	2.176	3.02	90.00	4.63	29.72	90.00	8.39
288.79	2.878	4.03	90.00	3.62	29.72	90.00	8.39
398.42	3.958	5.77	90.00	1.88	29.72	90.00	8.39
509.99	5.038	7.66	90.00	-0.01	29.72	90.00	8.39
623.44	6.114	9.73	90.00	-2.08	29.72	90.00	8.39
772.15	7.483	12.64	90.00	-4.99	29.72	90.00	8.39
863.49	8.276	14.51	90.00	-6.86	29.72	90.00	8.39
984.63	9.352	17.00	90.00	-9.35	29.72	90.00	8.39
1122.58	10.438	19.90	90.00	-12.25	29.72	90.00	8.39
1207.19	11.005	21.52	90.00	-13.87	29.72	90.00	8.39

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT #13 NODE #40)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	9.87	0.00	9.87
288.79	2.878	13.01	0.00	13.01
398.42	3.958	17.94	0.00	17.94
509.99	5.038	22.97	0.00	22.97
623.44	6.114	28.08	0.00	28.08
772.15	7.483	34.78	0.00	34.78
863.49	8.276	38.89	0.00	38.89
984.63	9.352	44.35	0.00	44.35
1122.58	10.438	50.56	0.00	50.56
1207.19	11.005	54.37	0.00	54.37

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT #13 NODE #12)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
219.17	2.176	0.00	0.00	16.20
288.80	2.878	0.00	0.00	21.35
398.43	3.958	0.00	0.00	29.46
510.01	5.038	0.00	0.00	37.70
623.47	6.114	0.00	0.00	46.09
772.22	7.483	0.00	0.00	57.09
863.61	8.276	0.00	0.00	63.84
984.84	9.352	0.00	0.00	72.81
1122.97	10.438	0.00	0.00	83.02
1207.81	11.005	0.00	0.00	89.29

FLOW ANGLES
ELEMENT #13: TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #40) BETA FLUID [deg]	INLET(NODE #40) ALPHA (RMS) [deg]	INLET(NODE #40) DEVIATION ANGLE [deg]	DISCHARGE(NODE #12) BETA FLUID [deg]	DISCHARGE(NODE #12) ALPHA (RMS) [deg]	DISCHARGE(NODE #12) DEVIATION ANGLE [deg]
219.17	2.176	3.02	90.00	4.63	29.72	90.00	8.39
288.80	2.878	4.03	90.00	3.62	29.72	90.00	8.39
398.43	3.958	5.77	90.00	1.88	29.72	90.00	8.39
510.01	5.038	7.66	90.00	-0.01	29.72	90.00	8.39
623.47	6.114	9.73	90.00	-2.08	29.72	90.00	8.39
772.22	7.483	12.64	90.00	-4.99	29.72	90.00	8.39
863.61	8.276	14.51	90.00	-6.86	29.72	90.00	8.39
984.84	9.352	17.00	90.00	-9.35	29.72	90.00	8.39
1122.97	10.438	19.90	90.00	-12.25	29.72	90.00	8.39
1207.81	11.005	21.52	90.00	-13.87	29.72	90.00	8.39

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT #14 NODE #12)
IMPELLER SPEED[RPM] = 110000
URMS[ft/s] 806.32

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
219.17	2.176	0.02786	52.18	0.00	52.18	250.99
288.80	2.878	0.03638	68.15	0.00	68.15	327.79
398.43	3.958	0.05001	93.68	0.00	93.68	450.57
510.01	5.038	0.06393	119.76	0.00	119.76	576.03
623.47	6.114	0.07817	146.43	0.00	146.43	704.31
772.22	7.483	0.09702	181.75	0.00	181.75	874.17
863.61	8.276	0.10828	202.85	0.00	202.85	975.67
984.84	9.352	0.12377	231.87	0.00	231.87	1115.25
1122.97	10.438	0.14071	263.60	0.00	263.60	1267.87
1207.81	11.005	0.15091	282.70	0.00	282.70	1359.71

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT #14 NODE #13)
IMPELLER SPEED[RPM] 110000
URMS[ft/s] = 1873.36

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
236.13	2.176	0.02986	55.95	1471.80	1472.87	111.89
305.46	2.878	0.03900	73.07	1430.75	1432.62	146.13
418.25	3.958	0.05361	100.43	1368.29	1371.98	200.87
534.01	5.038	0.06854	128.40	1307.86	1314.15	256.80
653.05	6.114	0.08380	156.99	1249.06	1258.89	313.98
812.34	7.483	0.10401	194.86	1175.13	1191.18	389.71
904.75	8.276	0.11609	217.48	1132.83	1153.52	434.96
1036.73	9.352	0.13270	248.59	1076.63	1104.97	497.18
1174.92	10.438	0.15086	282.61	1017.55	1056.08	565.22
1256.23	11.005	0.16179	303.08	983.08	1028.74	606.17

FLOW ANGLES
ELEMENT #14: IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #12) BETA FLUID [deg]	INLET(NODE #12) ALPHA (RMS) [deg]	INLET(NODE #12) DEVIATION ANGLE [deg]	DISCHARGE(NODE #13) BETA FLUID [deg]	DISCHARGE(NODE #13) ALPHA (RMS) [deg]	DISCHARGE(NODE #13) DEVIATION ANGLE [deg]
236.13	2.176	3.70	90.00	8.30	7.93	2.18	22.07
305.46	2.878	4.83	90.00	7.17	9.37	2.92	20.63
418.25	3.958	6.63	90.00	5.37	11.25	4.20	18.75
534.01	5.038	8.45	90.00	3.55	12.79	5.61	17.21
653.05	6.114	10.29	90.00	1.71	14.12	7.16	15.88
812.34	7.483	12.70	90.00	-0.70	15.59	9.41	14.41
904.75	8.276	14.12	90.00	-2.12	16.37	10.87	13.63
1036.73	9.352	16.04	90.00	-4.04	17.33	13.00	12.67
1174.92	10.438	18.10	90.00	-6.10	18.27	15.52	11.73
1256.23	11.005	19.32	90.00	-7.32	18.80	17.13	11.20

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT #15 NODE #13)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
236.43	2.176	0.02962	55.48	1471.80	1472.85
305.69	2.878	0.03829	71.74	1430.75	1432.56
418.51	3.958	0.05243	98.21	1368.29	1371.82
534.32	5.038	0.06693	125.39	1307.86	1313.86
653.46	6.114	0.08186	153.35	1249.06	1258.44
813.00	7.483	0.10184	190.79	1175.13	1190.53
904.92	8.276	0.11336	212.36	1132.83	1152.56
1037.17	9.352	0.12992	243.40	1076.63	1103.81
1175.54	10.438	0.14726	275.87	1017.55	1054.29
1257.28	11.005	0.15750	295.05	983.08	1026.40

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT #15 NODE #14)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
234.27	2.176	0.03198	59.91	1365.37	1366.69
303.06	2.878	0.04137	77.51	1327.29	1329.56
414.87	3.958	0.05664	106.10	1269.35	1273.78
529.68	5.038	0.07231	135.46	1213.28	1220.83
647.76	6.114	0.08843	165.66	1158.74	1170.52
805.75	7.483	0.11000	206.07	1090.16	1109.47
896.72	8.276	0.12242	229.33	1050.91	1075.64
1027.30	9.352	0.14024	262.73	998.78	1032.76
1163.86	10.438	0.15889	297.65	943.97	989.79
1243.92	11.005	0.16982	318.13	911.99	965.89

FLOW ANGLES
ELEMENT #15: VANLESS DIFFUSER

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #13) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE #14) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
234.27	2.176	2.16	2.16	-2.16	2.51	2.51	-2.51
303.06	2.878	2.87	2.87	-2.87	3.34	3.34	-3.34
414.87	3.958	4.11	4.11	-4.11	4.78	4.78	-4.78
529.68	5.038	5.48	5.48	-5.48	6.37	6.37	-6.37
647.76	6.114	7.00	7.00	-7.00	8.14	8.14	-8.14
805.75	7.483	9.22	9.22	-9.22	10.70	10.70	-10.70
896.72	8.276	10.62	10.62	-10.62	12.31	12.31	-12.31
1027.30	9.352	12.74	12.74	-12.74	14.74	14.74	-14.74
1163.86	10.438	15.17	15.17	-15.17	17.50	17.50	-17.50
1243.92	11.005	16.71	16.71	-16.71	19.23	19.23	-19.23

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT #16 NODE #14)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
234.25	2.176	0.03729	69.86	1365.37	1367.16
303.04	2.878	0.04825	90.38	1327.29	1330.37
414.86	3.958	0.06605	123.73	1269.35	1275.37
529.67	5.038	0.08432	157.97	1213.28	1223.53
647.76	6.114	0.10312	193.19	1158.74	1174.74
805.75	7.483	0.12828	240.31	1090.16	1116.33
896.71	8.276	0.14276	267.44	1050.91	1084.41
1027.29	9.352	0.16355	306.38	998.78	1044.72
1163.85	10.438	0.18529	347.11	943.97	1005.77
1243.91	11.005	0.19803	370.99	911.99	984.56

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT #16 NODE #15)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
217.76	2.176	0.03342	62.61	109.67	126.28
284.91	2.878	0.04373	81.91	143.49	165.22
392.32	3.958	0.06021	112.80	197.58	227.51
502.81	5.038	0.07717	144.56	253.23	291.59
616.95	6.114	0.09468	177.38	310.71	357.78
770.67	7.483	0.11828	221.57	388.13	446.92
860.01	8.276	0.13199	247.26	433.12	498.73
988.32	9.352	0.15168	284.15	497.74	573.14
1143.04	10.438	0.17542	328.63	575.67	662.87
1250.12	11.005	0.19186	359.42	629.59	724.96

FLOW ANGLES
ELEMENT #16: VANED DIFFUSER

IMPELLER SPEED[RPM] 110000

		INLET(NODE #14)			DISCHARGE(NODE #15)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
217.76	2.176	2.93	2.93	4.72	29.72	29.72	8.39
284.91	2.878	3.90	3.90	3.75	29.72	29.72	8.39
392.32	3.958	5.57	5.57	2.08	29.72	29.72	8.39
502.81	5.038	7.42	7.42	0.23	29.72	29.72	8.39
616.95	6.114	9.47	9.47	-1.82	29.72	29.72	8.39
770.67	7.483	12.43	12.43	-4.78	29.72	29.72	8.39
860.01	8.276	14.28	14.28	-6.63	29.72	29.72	8.39
988.32	9.352	17.05	17.05	-9.40	29.72	29.72	8.39
1143.04	10.438	20.19	20.19	-12.54	29.72	29.72	8.39
1250.12	11.005	22.14	22.14	-14.49	29.72	29.72	8.39

FLUID VELOCITIES
1-DISC. VOLUTE INLET
(ELEMENT #17 NODE #15)
IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
217.65	2.176	62.58	109.67	126.28
284.84	2.878	81.89	143.49	165.22
392.26	3.958	112.78	197.58	227.51
502.75	5.038	144.54	253.23	291.59
616.86	6.114	177.35	310.71	357.78
770.41	7.483	221.50	388.13	446.92
859.42	8.276	247.09	433.12	498.73
986.63	9.352	283.66	497.74	573.14
1142.46	10.438	328.47	575.67	662.87
1253.60	11.005	360.42	629.59	724.96

FLUID VELOCITIES
1-DISC. VOLUTE DISCHARGE
(ELEMENT #17 NODE #16)
IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
217.68	2.176	4.90	0.00	4.90
284.84	2.878	6.41	0.00	6.41
392.00	3.958	8.82	0.00	8.82
501.85	5.038	11.30	0.00	11.30
614.71	6.114	13.86	0.00	13.86
764.88	7.483	17.28	0.00	17.28
850.25	8.276	19.24	0.00	19.24
968.80	9.352	22.00	0.00	22.00
1110.06	10.438	25.34	0.00	25.34
1201.91	11.005	27.62	0.00	27.62

FLOW ANGLES
ELEMENT #17: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] = 110000

VOLUME	MASS	INLET(NODE #15)			DISCHARGE(NODE #16)		
FLOW RATE [GPM]	FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
217.68	2.176	29.72	29.72	4.72	90.00	90.00	8.39
284.84	2.878	29.72	29.72	3.75	90.00	90.00	8.39
392.00	3.958	29.72	29.72	2.08	90.00	90.00	8.39
501.85	5.038	29.72	29.72	0.23	90.00	90.00	8.39
614.71	6.114	29.72	29.72	-1.82	90.00	90.00	8.39
764.88	7.483	29.72	29.72	-4.78	90.00	90.00	8.39
850.25	8.276	29.72	29.72	-6.63	90.00	90.00	8.39
968.80	9.352	29.72	29.72	-9.40	90.00	90.00	8.39
1110.06	10.438	29.72	29.72	-12.54	90.00	90.00	8.39
1201.91	11.005	29.72	29.72	-14.49	90.00	90.00	8.39

NODAL PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) TOTAL HEAD [ft]	TEMP. [R]	NPSH AVAIL. [ft]	VAPOR PRES [PSIA]	STATIC PRES [PSIA]	DISCHARGE(NODE # 2) TOTAL HEAD [ft]	TEMP. [R]	STATIC PRES [PSIA]
228.18	2.176	6486.7	38.7	4978.5	20.687	198.8	21930.3	46.5	449.2
300.14	2.878	6487.5	38.7	5358.3	20.687	197.9	20438.3	45.8	442.1
411.20	3.958	6489.1	38.7	5836.5	20.687	196.0	17898.7	44.5	412.4
519.57	5.038	6491.1	38.7	6185.5	20.687	193.4	15144.6	43.2	365.3
626.89	6.114	6493.7	38.7	6404.7	20.687	190.3	12136.5	41.6	298.1
763.15	7.483	6497.8	38.7	6497.1	20.687	185.5	7910.7	39.4	183.4
842.11	8.276	6500.5	38.7	6454.8	20.687	182.3	5255.3	38.0	101.9
948.61	9.352	6504.6	38.7	6284.4	20.687	177.4	2257.0	36.3	0.0
1062.55	10.438	6509.4	38.7	5979.9	20.687	171.8	2991.1	36.8	0.0
1123.39	11.005	6512.1	38.7	5767.4	20.687	168.6	3545.8	37.1	0.0

ELEMENT LOSSES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
228.18	2.176	2320333.	0.01383	0.00252	0.00332	0.01968
300.14	2.878	3251086.	0.01035	0.00437	0.00258	0.01731
411.20	3.958	4205152.	0.00598	0.00822	0.00162	0.01582
519.57	5.038	5337799.	0.00280	0.01321	0.00090	0.01691
626.89	6.114	6465591.	0.00082	0.01935	0.00040	0.02056
763.15	7.483	7903599.	0.00001	0.02888	0.00005	0.02894
842.11	8.276	8738667.	0.00042	0.03527	0.00000	0.03569
948.61	9.352	9872561.	0.00202	0.04496	0.00000	0.04697
1062.55	10.438	11051985.	0.00485	0.05621	0.00000	0.06107
1123.39	11.005	11676413.	0.00683	0.06266	0.00000	0.06949

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 110000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
228.18	2.18	2320333.	0.1416	0.1613	0.8780	15443.5	257.6	-1.6
300.14	2.88	3251086.	0.1279	0.1452	0.8808	13950.8	250.3	-1.6
411.20	3.96	4205152.	0.1046	0.1204	0.8686	11409.6	221.6	-1.6
519.57	5.04	5337799.	0.0793	0.0962	0.8243	8653.4	175.5	-1.6
626.89	6.11	6465591.	0.0517	0.0723	0.7156	5642.8	110.2	-1.6
763.15	7.48	7903599.	0.0130	0.0419	0.3092	1413.0	-0.9	-1.6
842.11	8.28	8738667.	-0.0114	0.0243	-0.4703	-1245.2	-79.6	-1.6
948.61	9.35	9872561.	-0.0389	0.0005	-89.9281	-4247.7	-177.2	-1.6
1062.55	10.44	11051985.	-0.0323	-0.0249	3.4519	-3518.3	-171.2	-1.6
1123.39	11.01	11676413.	-0.0272	-0.0385	2.8059	-2966.3	-167.6	-1.6

ELEMENT LOSSES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
253.53	2.176	2081619.	0.00171	0.00231	0.24873	0.25275
329.04	2.878	2900969.	0.00193	0.00392	0.04689	0.05275
449.48	3.958	3577101.	0.00233	0.00729	0.00709	0.01671
569.72	5.038	4434067.	0.00282	0.01165	0.00150	0.01597
688.68	6.114	5243188.	0.00335	0.01698	0.00032	0.02065
839.45	7.483	6206976.	0.00408	0.02519	0.00003	0.02930
926.58	8.276	6726408.	0.00453	0.03068	0.00000	0.03522
1040.45	9.352	7370040.	0.00510	0.03881	0.00000	0.04391
1161.28	10.438	8364555.	0.00573	0.04853	0.00001	0.05427
1220.86	11.005	8916109.	0.00598	0.05396	0.00001	0.05996

ELEMENT LOSSES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
248.91	2.176	16052802.	0.00000	0.06905	0.00000	0.06905
323.14	2.878	15045241.	0.00000	0.04873	0.00000	0.04873
441.49	3.958	14423766.	0.00000	0.03124	0.00000	0.03124
559.87	5.038	13786844.	0.00000	0.02168	0.00000	0.02168
677.21	6.114	13197754.	0.00000	0.01585	0.00000	0.01585
825.99	7.483	12503782.	0.00000	0.01117	0.00000	0.01117
911.83	8.276	12125696.	0.00000	0.00929	0.00000	0.00929
1028.78	9.352	11656566.	0.00000	0.00739	0.00000	0.00739
1144.21	10.438	11146535.	0.00000	0.00593	0.00000	0.00593
1204.30	11.005	10899148.	0.00000	0.00532	0.00000	0.00532

ELEMENT LOSSES
ELEMENT # 4:VANED DIFFUSER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.56	2.176	2377049.	0.04623	0.00394	0.07008	0.12025
291.32	2.878	2797757.	0.02571	0.00664	0.06259	0.09494
402.02	3.958	4094150.	0.00553	0.01239	0.05142	0.06935
513.94	5.038	5183809.	0.00011	0.01994	0.04086	0.06092
626.81	6.114	6262623.	0.00889	0.02920	0.03120	0.06928
773.58	7.483	7628339.	0.03977	0.04347	0.02047	0.10371
860.07	8.276	8412774.	0.06745	0.05301	0.01523	0.13569
976.58	9.352	9477400.	0.11640	0.06751	0.00950	0.19341
1101.36	10.438	10507399.	0.17817	0.08360	0.00502	0.26679
1168.99	11.005	11042829.	0.21529	0.09267	0.00329	0.31125

ELEMENT LOSSES
ELEMENT # 5:TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.54	2.176	2469710.	0.00000	0.00089	0.00000	0.00089
290.90	2.878	3336446.	0.00000	0.00157	0.00000	0.00157
401.64	3.958	4639794.	0.00000	0.00299	0.00000	0.00299
513.53	5.038	5968383.	0.00000	0.00488	0.00000	0.00488
626.24	6.114	7319043.	0.00000	0.00726	0.00000	0.00726
772.47	7.483	9095922.	0.00000	0.01106	0.00000	0.01106
857.91	8.276	10128839.	0.00000	0.01366	0.00000	0.01366
976.23	9.352	11511220.	0.00000	0.01762	0.00000	0.01762
1100.68	10.438	13039581.	0.00000	0.02241	0.00000	0.02241
1168.04	11.005	13868331.	0.00000	0.02525	0.00000	0.02525

ELEMENT LOSSES
ELEMENT # 6:DOWNCOMER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.53	2.176	777120.	0.00000	0.00089	0.00000	0.00089
290.89	2.878	1048573.	0.00000	0.00157	0.00000	0.00157
401.60	3.958	1458826.	0.00000	0.00299	0.00000	0.00299
513.44	5.038	1876646.	0.00000	0.00488	0.00000	0.00488
626.07	6.114	2300750.	0.00000	0.00726	0.00000	0.00726
772.12	7.483	2856932.	0.00000	0.01106	0.00000	0.01106
857.41	8.276	3175698.	0.00000	0.01366	0.00000	0.01366
975.41	9.352	3612075.	0.00000	0.01762	0.00000	0.01762
1099.36	10.438	4084175.	0.00000	0.02241	0.00000	0.02241
1166.35	11.005	4338226.	0.00000	0.02525	0.00000	0.02525

ELEMENT LOSSES
ELEMENT # 7:TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.53	2.176	412778.	0.00000	0.00001	0.00000	0.00001
290.89	2.878	556971.	0.00000	0.00002	0.00000	0.00002
401.61	3.958	774757.	0.00000	0.00004	0.00000	0.00004
513.47	5.038	996490.	0.00000	0.00006	0.00000	0.00006
626.11	6.114	1221402.	0.00000	0.00009	0.00000	0.00009
772.21	7.483	1515991.	0.00000	0.00013	0.00000	0.00013
857.54	8.276	1684560.	0.00000	0.00016	0.00000	0.00016
975.62	9.352	1914765.	0.00000	0.00021	0.00000	0.00021
1099.71	10.438	2162970.	0.00000	0.00027	0.00000	0.00027
1166.80	11.005	2295941.	0.00000	0.00030	0.00000	0.00030

ELEMENT LOSSES
ELEMENT # 8:IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
244.48	2.176	1941481.	0.02206	0.00214	0.00196	0.02617
316.70	2.878	2711991.	0.01633	0.00366	0.00138	0.02138
433.28	3.958	3589449.	0.00904	0.00689	0.00075	0.01667
551.47	5.038	4606927.	0.00383	0.01117	0.00036	0.01537
670.93	6.114	5640888.	0.00081	0.01654	0.00014	0.01750
826.90	7.483	6999734.	0.00022	0.02514	0.00003	0.02539
920.25	8.276	7786746.	0.00166	0.03106	0.00001	0.03272
1036.10	9.352	8807617.	0.00554	0.03980	0.00000	0.04535
1163.87	10.438	9934910.	0.01227	0.05040	0.00000	0.06267
1232.17	11.005	10536103.	0.01697	0.05662	0.00001	0.07360

ELEMENT LOSSES
ELEMENT # 9:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
241.43	2.176	15077895.	0.00000	0.07219	0.00000	0.07219
312.96	2.878	14139557	0.00000	0.05120	0.00000	0.05120
428.25	3.958	13531600.	0.00000	0.03281	0.00000	0.03281
545.18	5.038	13006068.	0.00000	0.02264	0.00000	0.02264
663.42	6.114	12562352.	0.00000	0.01638	0.00000	0.01638
817.74	7.483	12092818.	0.00000	0.01131	0.00000	0.01131
910.18	8.276	11873225.	0.00000	0.00927	0.00000	0.00927
1026.25	9.352	11470005.	0.00000	0.00731	0.00000	0.00731
1153.86	10.438	11162881.	0.00000	0.00575	0.00000	0.00575
1222.55	11.005	11014858.	0.00000	0.00510	0.00000	0.00510

ELEMENT LOSSES
ELEMENT #10: VANED DIFFUSER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.47	2.176	2184114.	0.04874	0.00371	0.07017	0.12262
288.99	2.878	2628919.	0.02819	0.00624	0.06292	0.09735
398.59	3.958	3750166.	0.00703	0.01168	0.05187	0.07058
510.21	5.038	4793168.	0.00000	0.01894	0.04131	0.06025
623.82	6.114	5880304.	0.00724	0.02805	0.03152	0.06682
773.17	7.483	7363204.	0.03781	0.04264	0.02050	0.10095
863.23	8.276	8297401.	0.06727	0.05284	0.01501	0.13512
986.16	9.352	9413910.	0.11631	0.06724	0.00903	0.19259
1125.92	10.438	10746186.	0.18494	0.08511	0.00433	0.27437
1209.08	11.005	11493352.	0.22824	0.09564	0.00250	0.32638

ELEMENT LOSSES
ELEMENT #11. TURNING CHANNEL

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.17	2.176	2514821.	0.00000	0.00089	0.00000	0.00089
288.81	2.878	3287399.	0.00000	0.00154	0.00000	0.00154
398.45	3.958	4550240.	0.00000	0.00294	0.00000	0.00294
510.06	5.038	5873674.	0.00000	0.00481	0.00000	0.00481
623.58	6.114	7266149.	0.00000	0.00719	0.00000	0.00719
772.45	7.483	9181107.	0.00000	0.01104	0.00000	0.01104
863.94	8.276	10422365.	0.00000	0.01377	0.00000	0.01377
985.40	9.352	12044781.	0.00000	0.01798	0.00000	0.01798
1123.99	10.438	14088682.	0.00000	0.02344	0.00000	0.02344
1209.29	11.005	15448853.	0.00000	0.02706	0.00000	0.02706

ELEMENT LOSSES
ELEMENT #12: DOWNCOMER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.17	2.176	790470.	0.00000	0.00089	0.00000	0.00089
288.79	2.878	1034027.	0.00000	0.00154	0.00000	0.00154
398.42	3.958	1431740.	0.00000	0.00294	0.00000	0.00294
509.99	5.038	1848352.	0.00000	0.00481	0.00000	0.00481
623.44	6.114	2286332.	0.00000	0.00719	0.00000	0.00719
772.15	7.483	2886906.	0.00000	0.01104	0.00000	0.01104
863.49	8.276	3283781.	0.00000	0.01377	0.00000	0.01377
984.63	9.352	3788520.	0.00000	0.01798	0.00000	0.01798
1122.58	10.438	4425103.	0.00000	0.02344	0.00000	0.02344
1207.19	11.005	4864433.	0.00000	0.02706	0.00000	0.02706

ELEMENT LOSSES
ELEMENT #13: TURNING CHANNEL

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
219.17	2.176	419881.	0.00000	0.00001	0.00000	0.00001
288.80	2.878	549256.	0.00000	0.00002	0.00000	0.00002
398.43	3.958	760432.	0.00000	0.00004	0.00000	0.00004
510.01	5.038	981596.	0.00000	0.00006	0.00000	0.00006
623.47	6.114	1213993.	0.00000	0.00009	0.00000	0.00009
772.22	7.483	1532370.	0.00000	0.00013	0.00000	0.00013
863.61	8.276	1742510.	0.00000	0.00017	0.00000	0.00017
984.84	9.352	2009098.	0.00000	0.00022	0.00000	0.00022
1122.97	10.438	2344093.	0.00000	0.00028	0.00000	0.00028
1207.81	11.005	2573875.	0.00000	0.00032	0.00000	0.00032

ELEMENT LOSSES
ELEMENT #14: IMPELLER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
236.13	2.176	1943958.	0.02240	0.00207	0.00200	0.02647
305.46	2.878	2563128.	0.01680	0.00351	0.00143	0.02174
418.25	3.958	3476663.	0.00952	0.00661	0.00079	0.01691
534.01	5.038	4482303.	0.00420	0.01076	0.00038	0.01534
653.05	6.114	5544687.	0.00098	0.01605	0.00016	0.01719
812.34	7.483	7014085.	0.00017	0.02471	0.00003	0.02491
904.75	8.276	7960663.	0.00156	0.03078	0.00001	0.03234
1036.73	9.352	9201587.	0.00577	0.04021	0.00000	0.04598
1174.92	10.438	10706806.	0.01341	0.05197	0.00000	0.06539
1256.23	11.005	11726039.	0.01954	0.05978	0.00002	0.07933

ELEMENT LOSSES
ELEMENT #15: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
234.27	2.176	14136403.	0.00000	0.07514	0.00000	0.07514
303.06	2.878	13298746.	0.00000	0.05349	0.00000	0.05349
414.87	3.958	12714266.	0.00000	0.03432	0.00000	0.03432
529.68	5.038	12263288.	0.00000	0.02363	0.00000	0.02363
647.76	6.114	11915310.	0.00000	0.01700	0.00000	0.01700
805.75	7.483	11602226.	0.00000	0.01159	0.00000	0.01159
896.72	8.276	11430713.	0.00000	0.00946	0.00000	0.00946
1027.30	9.352	11283253.	0.00000	0.00727	0.00000	0.00727
1163.86	10.438	11138726.	0.00000	0.00560	0.00000	0.00560
1243.92	11.005	11104156.	0.00000	0.00485	0.00000	0.00485

ELEMENT LOSSES
ELEMENT #16: VANED DIFFUSER

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
217.76	2.176	2002229.	0.05089	0.00351	0.07037	0.12477
284.91	2.878	2437353.	0.03051	0.00586	0.06337	0.09974
392.32	3.958	3425061.	0.00864	0.01098	0.05252	0.07213
502.81	5.038	4402574.	0.00010	0.01789	0.04202	0.06001
616.95	6.114	5459916.	0.00557	0.02677	0.03212	0.06446
770.67	7.483	6985254.	0.03480	0.04144	0.02072	0.09696
860.01	8.276	7904501.	0.06297	0.05133	0.01519	0.12949
988.32	9.352	9317435.	0.11712	0.06739	0.00890	0.19342
1143.04	10.438	10915545.	0.19166	0.08663	0.00386	0.28216
1250.12	11.005	11965392.	0.24381	0.09915	0.00180	0.34476

ELEMENT LOSSES
ELEMENT #17: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
217.68	2.176	986640.	0.00146	0.00000	0.02622	0.02768
284.84	2.878	1266593.	0.00249	0.00000	0.02622	0.02872
392.00	3.958	1742793.	0.00473	0.00000	0.02622	0.03095
501.85	5.038	2253897	0.00777	0.00000	0.02622	0.03399
614.71	6.114	2809809.	0.01170	0.00000	0.02623	0.03792
764.88	7.483	3618463.	0.01825	0.00000	0.02623	0.04449
850.25	8.276	4102359.	0.02273	0.00000	0.02624	0.04897
968.80	9.352	4829136.	0.03002	0.00000	0.02625	0.05627
1110.06	10.438	5861683.	0.04015	0.00001	0.02627	0.06642
1201.91	11.005	6714980.	0.04802	0.00001	0.02628	0.07431

BOUNDARY/OPERATING CONDITIONS
ELEMENT #18: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.952		
IMP. INLET HUB DIAMETER [in]			1.351		
IMP. DISC. TIP DIAMETER [in]			3.900		
IMP. DISC. HUB DIAMETER [in]			3.900		
FRONT WEAR RING LEAKAGE COEF.			0.100		
FRONT WEAR RING CLEARANCE [in]			0.000		
FRONT WEAR RING DIAMETER [in]			6001.000		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #18: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
253.53	2.176	0.031565	0.00000	0.00000
329.04	2.878	0.041251	0.00000	0.00000
449.48	3.958	0.056326	0.00000	0.00000
569.72	5.038	0.071329	0.00000	0.00000
688.68	6.114	0.086184	0.00000	0.00000
839.45	7.483	0.105022	0.00000	0.00000
926.58	8.276	0.115911	0.00000	0.00000
1040.45	9.352	0.130355	0.00000	0.00000
1161.28	10.438	0.145776	0.00000	0.00000
1220.86	11.005	0.153714	0.00000	0.00000

BOUNDARY/OPERATING CONDITIONS
ELEMENT #19: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.952		
IMP. INLET HUB DIAMETER [in]			1.351		
IMP. DISC. TIP DIAMETER [in]			3.900		
IMP. DISC. HUB DIAMETER [in]			3.900		
FRONT WEAR RING LEAKAGE COEF.			0.100		
FRONT WEAR RING CLEARANCE [in]			0.000		
FRONT WEAR RING DIAMETER [in]			6001.000		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #19: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
244.48	2.176	0.030390	0.00000	0.00000
316.70	2.878	0.039837	0.00000	0.00000
433.28	3.958	0.054761	0.00000	0.00000
551.47	5.038	0.069860	0.00000	0.00000
670.93	6.114	0.085094	0.00000	0.00000
826.90	7.483	0.104914	0.00000	0.00000
920.25	8.276	0.116627	0.00000	0.00000
1036.10	9.352	0.132019	0.00000	0.00000
1163.87	10.438	0.148562	0.00000	0.00000
1232.17	11.005	0.157458	0.00000	0.00000

BOUNDARY/OPERATING CONDITIONS
ELEMENT #20: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.952		
IMP. INLET HUB DIAMETER [in]			1.351		
IMP. DISC. TIP DIAMETER [in]			3.900		
IMP. DISC. HUB DIAMETER [in]			3.900		
FRONT WEAR RING LEAKAGE COEF.			0.100		
FRONT WEAR RING CLEARANCE [in]			0.000		
FRONT WEAR RING DIAMETER [in]			6001.000		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #20: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 110000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
236.13	2.176	0.029864	0.00000	0.00000
305.46	2.878	0.039003	0.00000	0.00000
418.25	3.958	0.053612	0.00000	0.00000
534.01	5.038	0.068539	0.00000	0.00000
653.05	6.114	0.083802	0.00000	0.00000
812.34	7.483	0.104014	0.00000	0.00000
904.75	8.276	0.116090	0.00000	0.00000
1036.73	9.352	0.132698	0.00000	0.00000
1174.92	10.438	0.150858	0.00000	0.00000
1256.23	11.005	0.161786	0.00000	0.00000

Mark-48-F Small high-pressure 3 stage turbopump.

The Mark 48 pump is a high pressure, low capacity liquid hydrogen turbopump designed by the Rocketdyne Division of Rockwell International. This pump is intended to meet the requirements for small, high-performance, reusable, versatile, staged-combustion and expander-cycle rocket engine applications. The design speed for this pump is 9947 rad/sec, (95000 rpm). The Mark 48-F turbopump is required to operate at long durations, with long coast times between multiple starts, including off-design point operation. Therefore off-design performance analysis is a necessity that must be accomplished through expensive testing and/or reliable predictive methods. This model was chosen to demonstrate the wide range of off-design performance prediction capability that the CPAC code exhibits.

The CPAC pump model is configured with a first stage comprised of an **inducer** element followed by an **impeller** element including modeled **leakage**. The first stage impeller is followed by a **vaneless diffusing section** and a **vaned diffuser**. The stage crossover consisted of a **turning channel**, a **downcomer** and another **turning channel**. This turning channel leads into the second stage **impeller** and **leakage** elements, the **vaneless** and **vaned diffuser** followed by another stage crossover, (**turning channel, downcomer** and **turning channel**). The third stage **impeller** and **leakage** are followed by a **vaneless diffuser, a vaned diffuser** and a **single discharge volute**.

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET TO NODE	DISC. TO NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	LEAKAGE w/ FS FWR	3	2
4	VANLESS DIFFUSER	3	4
5	VANED DIFFUSER	4	5
6	TURNING CHANNEL	5	6
7	DOWNCOMER	6	7
8	TURNING CHANNEL	7	8
9	IMPELLER	8	9
10	LEAKAGE w/ FS FWR	9	8
11	VANLESS DIFFUSER	9	10
12	VANED DIFFUSER	10	11
13	TURNING CHANNEL	11	12
14	DOWNCOMER	12	13
15	TURNING CHANNEL	13	14
16	IMPELLER	14	15
17	LEAKAGE w/ FS FWR	15	14
18	VANLESS DIFFUSER	15	16
19	VANED DIFFUSER	16	17
20	1-DISC. VOLUTE	17	18

INLET FLUID PROPERTIES

FLUID DENSITY [lb/ft^3]	4.370
FLUID VISCOSITY [ft^2/s]	0.00000200

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 95000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
254.22	2.48	0.0362	1.8134	6.9204	0.2620	161383.1	4897.3	40.0
304.06	2.96	0.0423	1.8668	6.1337	0.3044	165869.4	5033.4	40.0
354.91	3.46	0.0485	1.9002	5.5384	0.3431	168546.1	5114.5	40.0
405.75	3.95	0.0547	1.9170	5.0799	0.3774	169712.2	5149.7	40.0
456.59	4.45	0.0609	1.9197	4.7151	0.4071	169591.3	5145.9	40.0
507.43	4.94	0.0671	1.9099	4.4167	0.4324	168316.5	5107.0	40.0
558.28	5.44	0.0733	1.8884	4.1666	0.4532	165971.1	5035.7	40.0
609.12	5.93	0.0795	1.8559	3.9529	0.4695	162609.8	4933.5	40.0
659.96	6.43	0.0858	1.8129	3.7673	0.4812	158269.2	4801.5	40.0
710.81	6.92	0.0920	1.7595	3.6037	0.4882	152973.6	4640.6	40.0

GEOMETRY
ELEMENT #1: INDUCER

INLET TIP DIAMETER [in]	1.96
INLET HUB DIAMETER [in]	1.12
INLET PASSAGE WIDTH [in]	0.42
INLET BLADE ANGLE [deg]	20
NUMBER OF INLET BLADES	6
INLET NORMAL THICKNESS [in]	0.015
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	1.9
DISCH. HUB DIAMETER [in]	1.12
DISCH. PASSAGE WIDTH [in]	0.39
DISCH. BLADE ANGLE [deg]	12.9
NUMBER OF DISCH. BLADES	6
DISCH. NORMAL THICKNESS [in]	0.015
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	0.684
SURFACE ROUGHNESS [in]	0.0001

GEOMETRY
ELEMENTS #2,9,16: IMPELLER

INLET TIP DIAMETER [in]	1.9
INLET HUB DIAMETER [in]	1.22
INLET PASSAGE WIDTH [in]	0.34
INLET BLADE ANGLE [deg]	26
NUMBER OF INLET BLADES	6
INLET NORMAL THICKNESS [in]	0.015
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	4.058
DISCH. HUB DIAMETER [in]	4.058
DISCH. PASSAGE WIDTH [in]	0.15
DISCH. BLADE ANGLE [deg]	37.5
NUMBER OF DISCH. BLADES	12
DISCH. NORMAL THICKNESS [in]	0.015
DISCH. BLOCKAGE	0.85
BLADE LENGTH [in]	2
SURFACE ROUGHNESS [in]	0.0001

BOUNDARY/OPERATING CONDITIONS
ELEMENTS #2,9,16: IMPELLER

MAX. EFFICIENCY HEAD COEF:				0.450	
MAX. EFF. IMPELLER DISCHARGE FLOW COEF:				0.071	
IMPELLER CLEARANCE TORQUE COEF:				0.010	
IMPELLER BLADE LOADING COEF (AA) .				-6328.568	
IMPELLER BLADE LOADING COEF (BB)				3143.020	
IMPELLER BLADE LOADING COEF (CC) .				-370.300	
IMPELLER FRONT SHROUD CLEARANCE [in]				0.0500	
IMPELLER REAR SHROUD CLEARANCE [in]				0.0500	
INLET PRESSURE [PSIA]				0.00	
INLET BYPASS FLOW RATE [%]				0.00	
INLET CU [ft/s]	432.55	393.45	353.56	313.68	273.80
	233.92	194.04	154.15	114.27	74.39
INLET TEMP. [R]	40.00	40.00	40.00	40.00	40.00
	40.00	40.00	40.00	40.00	40.00

GEOMETRY
ELEMENTS #4,11,18: VANLESS DIFFUSER

INLET TIP DIAMETER [in]	4.058
INLET HUB DIAMETER [in]	4.058
INLET PASSAGE WIDTH [in]	0.15
INLET BLOCKAGE	0.85
DISCH. TIP DIAMETER [in]	4.36
DISCH. HUB DIAMETER [in]	4.36
DISCH. PASSAGE WIDTH [in]	0.15
DISCH. BLOCKAGE	0.85
SURFACE ROUGHNESS [in]	0.0001

GEOMETRY
ELEMENTS #5,12,19,: VANED DIFFUSER

INLET TIP DIAMETER [in]	4.36
INLET HUB DIAMETER [in]	4.36
INLET PASSAGE WIDTH [in]	0.15
INLET BLADE ANGLE [deg]	5
NUMBER OF INLET VANES	11
INLET NORMAL THICKNESS [in]	0.015
INLET BLOCKAGE	0.85
DISCH. TIP DIAMETER [in]	5.48
DISCH. HUB DIAMETER [in]	5.48
DISCH. PASSAGE WIDTH [in]	0.15
DISCH. BLADE ANGLE [deg]	18
NUMBER OF DISCH. VANES	11
DISCH. NORMAL THICKNESS [in]	0.015
DISCH. BLOCKAGE	0.9
VANE LENGTH [in]	1.12
SURFACE ROUGHNESS [in]	0.0001

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 3: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.008		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 3:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
300.64	2.928	0.036244	0.44464	0.02894
350.88	3.417	0.042300	0.44701	0.02480
402.18	3.916	0.048486	0.45003	0.02164
453.56	4.417	0.054680	0.45377	0.01918
505.02	4.918	0.060883	0.45823	0.01723
556.55	5.420	0.067094	0.46339	0.01563
608.14	5.922	0.073315	0.46925	0.01431
659.81	6.425	0.079543	0.47577	0.01319
711.54	6.929	0.085780	0.48294	0.01223
763.34	7.433	0.092024	0.49074	0.01140

GEOMETRY
ELEMENTS #6,13,: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.544
DISCH. HYDRAULIC DIAMETER[in]	0.544
PASSAGE LENGTH [in]	1.58
SURFACE ROUGHNESS[in]	0.0001
NUMBER OF CHANNELS	11
BLOCKAGE	0.9

GEOMETRY
ELEMENTS #7,14: DOWNCOMER

INLET HYDRAULIC DIAMETER[in]	0.544
DISCH. HYDRAULIC DIAMETER[in]	0.544
PASSAGE LENGTH [in]	2.34
SURFACE ROUGHNESS[in]	0.0001
NUMBER OF DOWNCOMERS	11
BLOCKAGE	0.9

GEOMETRY
ELEMENTS #8,15: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.544
DISCH. HYDRAULIC DIAMETER[in]	0.544
PASSAGE LENGTH [in]	1.2
SURFACE ROUGHNESS[in]	0.0001
NUMBER OF CHANNELS	11
BLOCKAGE	0.9

BOUNDARY/OPERATING CONDITIONS
ELEMENT #10: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP. DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.007		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #10: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
304.08	2.961	0.036658	0.48183	0.02862
353.93	3.447	0.042668	0.48119	0.02459
404.76	3.941	0.048796	0.48026	0.02150
455.55	4.436	0.054920	0.47908	0.01910
506.33	4.931	0.061040	0.47764	0.01719
557.07	5.425	0.067158	0.47596	0.01562
607.80	5.919	0.073273	0.47404	0.01432
658.49	6.412	0.079385	0.47189	0.01321
709.17	6.906	0.085494	0.46952	0.01227
759.82	7.399	0.091601	0.46692	0.01145

BOUNDARY/OPERATING CONDITIONS
ELEMENT #17: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP. DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.006		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #17: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
293.20	2.855	0.035347	0.37966	0.02968
343.00	3.340	0.041351	0.37920	0.02537
393.78	3.835	0.047472	0.37851	0.02210
444.53	4.329	0.053590	0.37763	0.01957
495.26	4.823	0.059706	0.37654	0.01757
545.97	5.317	0.065820	0.37525	0.01594
596.66	5.810	0.071931	0.37379	0.01458
647.34	6.304	0.078040	0.37213	0.01344
697.99	6.797	0.084147	0.37030	0.01247
748.63	7.290	0.090251	0.36830	0.01162

GEOMETRY

ELEMENT #20: 1-DISC. VOLUTE

THROAT DIAMETER [in]	2.3
THROAT AREA [in^2]	4.15
BLOCKAGE	0.9
SURFACE ROUGHNESS	0.0001

FLUID VELOCITIES
INDUCER INLET
(ELEMENT # 1 NODE # 1)
IMPELLER SPEED[RPM] 95000
URMS[ft/s] 662.20

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
254.98	2.483	0.02829	47.62	0.00	47.62	139.22
304.98	2.970	0.03383	56.95	0.00	56.95	166.52
355.97	3.466	0.03949	66.48	0.00	66.48	194.37
406.97	3.963	0.04515	76.00	0.00	76.00	222.21
457.96	4.460	0.05080	85.52	0.00	85.52	250.05
508.96	4.956	0.05646	95.05	0.00	95.05	277.90
559.96	5.453	0.06212	104.57	0.00	104.57	305.74
610.95	5.949	0.06777	114.09	0.00	114.09	333.59
661.95	6.446	0.07343	123.62	0.00	123.62	361.43
712.94	6.943	0.07909	133.14	0.00	133.14	389.28

FLUID VELOCITIES
INDUCER DISCHARGE
(ELEMENT # 1 NODE # 2)
IMPELLER SPEED[RPM] 95000
URMS[ft/s] = 646.98

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
254.98	2.483	0.03223	54.26	442.83	446.14	243.05
304.98	2.970	0.03855	64.90	402.80	407.99	290.71
355.97	3.466	0.04500	75.75	361.97	369.81	339.32
406.97	3.963	0.05145	86.61	321.14	332.61	387.93
457.96	4.460	0.05789	97.46	280.31	296.77	436.54
508.96	4.956	0.06434	108.31	239.48	262.83	485.15
559.96	5.453	0.07078	119.16	198.65	231.65	533.76
610.95	5.949	0.07723	130.01	157.82	204.48	582.37
661.95	6.446	0.08368	140.87	116.99	183.11	630.98
712.94	6.943	0.09012	151.72	76.16	169.76	679.59

FLOW ANGLES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 95000

		INLET(NODE # 1)			DISCHARGE(NODE # 2)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.980	2.483	4.11	90.00	15.89	14.88	6.99	-1.98
304.976	2.970	4.92	90.00	15.08	14.88	9.15	-1.98
355.972	3.466	5.73	90.00	14.27	14.88	11.82	-1.98
406.968	3.963	6.55	90.00	13.45	14.88	15.09	-1.98
457.964	4.460	7.36	90.00	12.64	14.88	19.17	-1.98
508.960	4.956	8.17	90.00	11.83	14.88	24.34	-1.98
559.956	5.453	8.97	90.00	11.03	14.88	30.96	-1.98
610.952	5.949	9.78	90.00	10.22	14.88	39.48	-1.98
661.948	6.446	10.57	90.00	9.43	14.88	50.29	-1.98
712.944	6.943	11.37	90.00	8.63	14.88	63.34	-1.98

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 2 NODE # 2)
IMPELLER SPEED[RPM] 95000
URMS[ft/s] 662.35

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
300.64	2.928	0.04008	67.47	432.55	437.78	153.90
350.88	3.417	0.04677	78.74	393.45	401.25	179.62
402.18	3.916	0.05361	90.26	353.56	364.90	205.89
453.56	4.417	0.06046	101.79	313.68	329.78	232.19
505.02	4.918	0.06732	113.33	273.80	296.33	258.53
556.55	5.420	0.07419	124.90	233.92	265.17	284.91
608.14	5.922	0.08107	136.48	194.04	237.22	311.32
659.81	6.425	0.08796	148.07	154.15	213.75	337.77
711.54	6.929	0.09485	159.68	114.27	196.36	364.26
763.34	7.433	0.10176	171.30	74.39	186.76	390.77

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 2 NODE # 3)
IMPELLER SPEED[RPM] = 95000
URMS[ft/s] 1683.45

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
300.64	2.928	0.03624	61.01	1399.18	1400.51	100.23
350.88	3.417	0.04230	71.21	1380.26	1382.10	116.98
402.18	3.916	0.04849	81.62	1361.34	1363.79	134.08
453.56	4.417	0.05468	92.05	1342.76	1345.92	151.21
505.02	4.918	0.06088	102.49	1324.50	1328.47	168.36
556.55	5.420	0.06709	112.95	1306.54	1311.42	185.54
608.14	5.922	0.07331	123.42	1288.86	1294.76	202.74
659.81	6.425	0.07954	133.91	1271.43	1278.47	219.97
711.54	6.929	0.08578	144.41	1254.25	1262.54	237.21
763.34	7.433	0.09202	154.92	1237.31	1246.97	254.48

FLOW ANGLES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 2) BETA FLUID [deg]	INLET(NODE # 2) ALPHA (RMS) [deg]	INLET(NODE # 2) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 3) BETA FLUID [deg]	DISCHARGE(NODE # 3) ALPHA (RMS) [deg]	DISCHARGE(NODE # 3) DEVIATION ANGLE [deg]
300.639	2.928	16.36	8.87	9.64	12.11	2.50	25.39
350.879	3.417	16.32	11.32	9.68	13.22	2.95	24.28
402.185	3.916	16.29	14.32	9.71	14.22	3.43	23.28
453.565	4.417	16.27	17.98	9.73	15.12	3.92	22.38
505.019	4.918	16.26	22.49	9.74	15.94	4.42	21.56
556.545	5.420	16.25	28.10	9.75	16.68	4.94	20.82
608.142	5.922	16.25	35.12	9.75	17.37	5.47	20.13
659.808	6.425	16.24	43.85	9.76	18.00	6.01	19.50
711.540	6.929	16.24	54.41	9.76	18.60	6.57	18.90
763.337	7.433	16.24	66.53	9.76	19.15	7.14	18.35

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 4 NODE # 3)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.02986	50.26	1399.18	1400.08
304.52	2.965	0.03571	60.12	1380.26	1381.57
355.44	3.461	0.04168	70.17	1361.34	1363.15
406.36	3.957	0.04765	80.22	1342.76	1345.16
457.28	4.453	0.05362	90.27	1324.50	1327.58
508.20	4.949	0.05959	100.32	1306.54	1310.39
559.12	5.445	0.06557	110.38	1288.86	1293.58
610.04	5.940	0.07154	120.43	1271.43	1277.13
660.96	6.436	0.07751	130.48	1254.25	1261.03
711.88	6.932	0.08348	140.53	1237.31	1245.27

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 4 NODE # 4)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.02779	46.78	1302.26	1303.11
304.52	2.965	0.03324	55.95	1284.66	1285.88
355.44	3.461	0.03879	65.31	1267.05	1268.73
406.36	3.957	0.04435	74.66	1249.76	1251.99
457.28	4.453	0.04991	84.02	1232.76	1235.63
508.20	4.949	0.05547	93.37	1216.04	1219.63
559.12	5.445	0.06102	102.73	1199.58	1203.98
610.04	5.940	0.06658	112.09	1183.36	1188.67
660.96	6.436	0.07214	121.44	1167.38	1173.68
711.88	6.932	0.07770	130.80	1151.61	1159.01

FLOW ANGLES
ELEMENT # 4:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 3) BETA FLUID [deg]	INLET(NODE # 3) ALPHA (RMS) [deg]	INLET(NODE # 3) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 4) BETA FLUID [deg]	DISCHARGE(NODE # 4) ALPHA (RMS) [deg]	DISCHARGE(NODE # 4) DEVIATION ANGLE [deg]
254.598	2.479	2.06	2.06	-2.06	2.06	2.06	-2.06
304.519	2.965	2.49	2.49	-2.49	2.49	2.49	-2.49
355.438	3.461	2.95	2.95	-2.95	2.95	2.95	-2.95
406.358	3.957	3.42	3.42	-3.42	3.42	3.42	-3.42
457.277	4.453	3.90	3.90	-3.90	3.90	3.90	-3.90
508.197	4.949	4.39	4.39	-4.39	4.39	4.39	-4.39
559.116	5.445	4.89	4.89	-4.89	4.89	4.89	-4.89
610.036	5.940	5.41	5.41	-5.41	5.41	5.41	-5.41
660.956	6.436	5.94	5.94	-5.94	5.94	5.94	-5.94
711.875	6.932	6.48	6.48	-6.48	6.48	6.48	-6.48

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT # 5 NODE # 4)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.03318	55.86	1302.26	1303.46
304.52	2.965	0.03969	66.82	1284.66	1286.40
355.44	3.461	0.04633	77.99	1267.05	1269.45
406.36	3.957	0.05296	89.16	1249.76	1252.94
457.28	4.453	0.05960	100.33	1232.76	1236.84
508.20	4.949	0.06624	111.51	1216.04	1221.15
559.12	5.445	0.07287	122.68	1199.58	1205.84
610.04	5.940	0.07951	133.85	1183.36	1190.92
660.96	6.436	0.08615	145.02	1167.38	1176.36
711.88	6.932	0.09278	156.20	1151.61	1162.15

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT # 5 NODE # 5)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.02163	36.41	145.97	150.44
304.52	2.965	0.02587	43.54	174.59	179.93
355.44	3.461	0.03019	50.82	203.78	210.02
406.36	3.957	0.03452	58.11	232.97	240.11
457.28	4.453	0.03884	65.39	262.17	270.20
508.20	4.949	0.04317	72.67	291.36	300.28
559.12	5.445	0.04749	79.95	320.55	330.37
610.04	5.940	0.05182	87.23	349.74	360.46
660.96	6.436	0.05614	94.51	378.94	390.55
711.88	6.932	0.06047	101.79	408.13	420.63

FLOW ANGLES
ELEMENT # 5:VANED DIFFUSER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 4) BETA FLUID [deg]	INLET(NODE # 4) ALPHA (RMS) [deg]	INLET(NODE # 4) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 5) BETA FLUID [deg]	DISCHARGE(NODE # 5) ALPHA (RMS) [deg]	DISCHARGE(NODE # 5) DEVIATION ANGLE [deg]
254.598	2.479	2.46	2.46	2.54	14.00	14.00	4.00
304.519	2.965	2.98	2.98	2.02	14.00	14.00	4.00
355.438	3.461	3.52	3.52	1.48	14.00	14.00	4.00
406.358	3.957	4.08	4.08	0.92	14.00	14.00	4.00
457.277	4.453	4.65	4.65	0.35	14.00	14.00	4.00
508.197	4.949	5.24	5.24	-0.24	14.00	14.00	4.00
559.116	5.445	5.84	5.84	-0.84	14.00	14.00	4.00
610.036	5.940	6.45	6.45	-1.45	14.00	14.00	4.00
660.956	6.436	7.08	7.08	-2.08	14.00	14.00	4.00
711.875	6.932	7.72	7.72	-2.72	14.00	14.00	4.00

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 6 NODE # 5)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	35.50	145.97	150.22
304.52	2.965	42.47	174.59	179.68
355.44	3.461	49.57	203.78	209.72
406.36	3.957	56.67	232.97	239.76
457.28	4.453	63.77	262.17	269.81
508.20	4.949	70.87	291.36	299.85
559.12	5.445	77.97	320.55	329.90
610.04	5.940	85.07	349.74	359.94
660.96	6.436	92.17	378.94	389.99
711.88	6.932	99.27	408.13	420.03

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 6 NODE # 6)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.00	0.00	150.22
304.52	2.965	0.00	0.00	179.68
355.44	3.461	0.00	0.00	209.72
406.36	3.957	0.00	0.00	239.76
457.28	4.453	0.00	0.00	269.81
508.20	4.949	0.00	0.00	299.85
559.12	5.445	0.00	0.00	329.90
610.04	5.940	0.00	0.00	359.94
660.96	6.436	0.00	0.00	389.99
711.88	6.932	0.00	0.00	420.03

FLOW ANGLES
ELEMENT # 6:TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 5) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 6) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.598	2.479	2.46	2.46	2.54	14.00	14.00	4.00
304.519	2.965	2.98	2.98	2.02	14.00	14.00	4.00
355.438	3.461	3.52	3.52	1.48	14.00	14.00	4.00
406.358	3.957	4.08	4.08	0.92	14.00	14.00	4.00
457.277	4.453	4.65	4.65	0.35	14.00	14.00	4.00
508.197	4.949	5.24	5.24	-0.24	14.00	14.00	4.00
559.116	5.445	5.84	5.84	-0.84	14.00	14.00	4.00
610.036	5.940	6.45	6.45	-1.45	14.00	14.00	4.00
660.956	6.436	7.08	7.08	-2.08	14.00	14.00	4.00
711.875	6.932	7.72	7.72	-2.72	14.00	14.00	4.00

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT # 7 NODE # 6)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.00	0.00	35.50
304.52	2.965	0.00	0.00	42.47
355.44	3.461	0.00	0.00	49.57
406.36	3.957	0.00	0.00	56.67
457.28	4.453	0.00	0.00	63.77
508.20	4.949	0.00	0.00	70.87
559.12	5.445	0.00	0.00	77.97
610.04	5.940	0.00	0.00	85.07
660.96	6.436	0.00	0.00	92.17
711.88	6.932	0.00	0.00	99.27

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT # 7 NODE # 7)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.00	0.00	35.50
304.52	2.965	0.00	0.00	42.47
355.44	3.461	0.00	0.00	49.57
406.36	3.957	0.00	0.00	56.67
457.28	4.453	0.00	0.00	63.77
508.20	4.949	0.00	0.00	70.87
559.12	5.445	0.00	0.00	77.97
610.04	5.940	0.00	0.00	85.07
660.96	6.436	0.00	0.00	92.17
711.88	6.932	0.00	0.00	99.27

FLOW ANGLES
ELEMENT # 7:DOWNCOMER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 6) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 7) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.598	2.479	2.46	90.00	2.54	14.00	90.00	4.00
304.519	2.965	2.98	90.00	2.02	14.00	90.00	4.00
355.438	3.461	3.52	90.00	1.48	14.00	90.00	4.00
406.358	3.957	4.08	90.00	0.92	14.00	90.00	4.00
457.277	4.453	4.65	90.00	0.35	14.00	90.00	4.00
508.197	4.949	5.24	90.00	-0.24	14.00	90.00	4.00
559.116	5.445	5.84	90.00	-0.84	14.00	90.00	4.00
610.036	5.940	6.45	90.00	-1.45	14.00	90.00	4.00
660.956	6.436	7.08	90.00	-2.08	14.00	90.00	4.00
711.875	6.932	7.72	90.00	-2.72	14.00	90.00	4.00

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 8 NODE # 7)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	35.50	0.00	35.50
304.52	2.965	42.47	0.00	42.47
355.44	3.461	49.57	0.00	49.57
406.36	3.957	56.67	0.00	56.67
457.28	4.453	63.77	0.00	63.77
508.20	4.949	70.87	0.00	70.87
559.12	5.445	77.97	0.00	77.97
610.04	5.940	85.07	0.00	85.07
660.96	6.436	92.17	0.00	92.17
711.88	6.932	99.27	0.00	99.27

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 8 NODE # 8)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.60	2.479	0.00	0.00	35.50
304.52	2.965	0.00	0.00	42.47
355.44	3.461	0.00	0.00	49.57
406.36	3.957	0.00	0.00	56.67
457.28	4.453	0.00	0.00	63.77
508.20	4.949	0.00	0.00	70.87
559.12	5.445	0.00	0.00	77.97
610.04	5.940	0.00	0.00	85.07
660.96	6.436	0.00	0.00	92.17
711.88	6.932	0.00	0.00	99.27

FLOW ANGLES
ELEMENT # 8:TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

		INLET(NODE # 7)			DISCHARGE(NODE # 8)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.598	2.479	2.46	90.00	2.54	14.00	90.00	4.00
304.519	2.965	2.98	90.00	2.02	14.00	90.00	4.00
355.438	3.461	3.52	90.00	1.48	14.00	90.00	4.00
406.358	3.957	4.08	90.00	0.92	14.00	90.00	4.00
457.277	4.453	4.65	90.00	0.35	14.00	90.00	4.00
508.197	4.949	5.24	90.00	-0.24	14.00	90.00	4.00
559.116	5.445	5.84	90.00	-0.84	14.00	90.00	4.00
610.036	5.940	6.45	90.00	-1.45	14.00	90.00	4.00
660.956	6.436	7.08	90.00	-2.08	14.00	90.00	4.00
711.875	6.932	7.72	90.00	-2.72	14.00	90.00	4.00

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 9 NODE # 8)
IMPELLER SPEED[RPM] 95000
URMS[ft/s] 662.35

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
304.08	2.961	0.04054	68.24	0.00	68.24	155.67
353.93	3.447	0.04718	79.43	0.00	79.43	181.19
404.76	3.941	0.05396	90.83	0.00	90.83	207.21
455.55	4.436	0.06073	102.23	0.00	102.23	233.21
506.33	4.931	0.06750	113.63	0.00	113.63	259.20
557.07	5.425	0.07426	125.01	0.00	125.01	285.18
607.80	5.919	0.08102	136.40	0.00	136.40	311.15
658.49	6.412	0.08778	147.77	0.00	147.77	337.10
709.17	6.906	0.09454	159.15	0.00	159.15	363.04
759.82	7.399	0.10129	170.51	0.00	170.51	388.97

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 9 NODE # 9)
IMPELLER SPEED[RPM] = 95000
URMS[ft/s] 1683.45

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
304.08	2.961	0.03666	61.71	1397.87	1399.24	101.37
353.93	3.447	0.04267	71.83	1379.12	1381.00	117.99
404.76	3.941	0.04880	82.15	1360.40	1362.89	134.94
455.55	4.436	0.05492	92.45	1342.05	1345.24	151.87
506.33	4.931	0.06104	102.76	1324.04	1328.03	168.80
557.07	5.425	0.06716	113.06	1306.36	1311.25	185.72
607.80	5.919	0.07327	123.35	1288.97	1294.87	202.63
658.49	6.412	0.07939	133.64	1271.87	1278.88	219.53
709.17	6.906	0.08549	143.93	1255.04	1263.27	236.42
759.82	7.399	0.09160	154.21	1238.45	1248.02	253.31

FLOW ANGLES
ELEMENT # 9:IMPELLER

IMPELLER SPEED[RPM] - 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 8) BETA FLUID [deg]	INLET(NODE # 8) ALPHA (RMS) [deg]	INLET(NODE # 8) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 9) BETA FLUID [deg]	DISCHARGE(NODE # 9) ALPHA (RMS) [deg]	DISCHARGE(NODE # 9) DEVIATION ANGLE [deg]
304.078	2.961	5.88	90.00	20.12	12.19	2.53	25.31
353.933	3.447	6.84	90.00	19.16	13.28	2.98	24.22
404.757	3.941	7.81	90.00	18.19	14.27	3.46	23.23
455.555	4.436	8.77	90.00	17.23	15.15	3.94	22.35
506.327	4.931	9.73	90.00	16.27	15.96	4.44	21.54
557.073	5.425	10.69	90.00	15.31	16.69	4.95	20.81
607.796	5.919	11.64	90.00	14.36	17.36	5.47	20.14
658.495	6.412	12.58	90.00	13.42	17.99	6.00	19.51
709.170	6.906	13.51	90.00	12.49	18.57	6.54	18.93
759.823	7.399	14.44	90.00	11.56	19.11	7.10	18.39

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT #11 NODE # 9)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02981	50.19	1397.87	1398.77
304.06	2.961	0.03566	60.03	1379.12	1380.43
354.91	3.456	0.04162	70.06	1360.40	1362.21
405.75	3.951	0.04758	80.10	1342.05	1344.44
456.59	4.446	0.05354	90.14	1324.04	1327.11
507.43	4.941	0.05950	100.17	1306.36	1310.20
558.28	5.436	0.06547	110.21	1288.97	1293.68
609.12	5.932	0.07143	120.25	1271.87	1277.55
659.96	6.427	0.07739	130.28	1255.04	1261.78
710.81	6.922	0.08335	140.32	1238.45	1246.38

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT #11 NODE #10)
IMPELLER SPEED[RPM] - 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02775	46.71	1301.04	1301.89
304.06	2.961	0.03319	55.87	1283.60	1284.82
354.91	3.456	0.03874	65.21	1266.17	1267.86
405.75	3.951	0.04428	74.55	1249.09	1251.32
456.59	4.446	0.04983	83.89	1232.33	1235.19
507.43	4.941	0.05538	93.23	1215.87	1219.45
558.28	5.436	0.06093	102.58	1199.69	1204.07
609.12	5.932	0.06648	111.92	1183.77	1189.06
659.96	6.427	0.07203	121.26	1168.10	1174.39
710.81	6.922	0.07758	130.60	1152.67	1160.05

FLOW ANGLES
ELEMENT #11: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 9) BETA FLUID [deg]	INLET(NODE # 9) ALPHA (RMS) [deg]	INLET(NODE # 9) DEVIATION ANGLE [deg]	DISCHARGE(NODE #10) BETA FLUID [deg]	DISCHARGE(NODE #10) ALPHA (RMS) [deg]	DISCHARGE(NODE #10) DEVIATION ANGLE [deg]
254.216	2.476	2.06	2.06	-2.06	2.06	2.06	-2.06
304.062	2.961	2.49	2.49	-2.49	2.49	2.49	-2.49
354.905	3.456	2.95	2.95	-2.95	2.95	2.95	-2.95
405.748	3.951	3.42	3.42	-3.42	3.42	3.42	-3.42
456.591	4.446	3.89	3.89	-3.89	3.89	3.89	-3.89
507.435	4.941	4.38	4.38	-4.38	4.38	4.38	-4.38
558.278	5.436	4.89	4.89	-4.89	4.89	4.89	-4.89
609.121	5.932	5.40	5.40	-5.40	5.40	5.40	-5.40
659.964	6.427	5.93	5.93	-5.93	5.93	5.93	-5.93
710.807	6.922	6.46	6.46	-6.46	6.46	6.46	-6.46

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT #12 NODE #10)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.03313	55.78	1301.04	1302.24
304.06	2.961	0.03963	66.72	1283.60	1285.34
354.91	3.456	0.04626	77.87	1266.17	1268.57
405.75	3.951	0.05288	89.03	1249.09	1252.27
456.59	4.446	0.05951	100.18	1232.33	1236.40
507.43	4.941	0.06614	111.34	1215.87	1220.96
558.28	5.436	0.07276	122.49	1199.69	1205.93
609.12	5.932	0.07939	133.65	1183.77	1191.30
659.96	6.427	0.08602	144.81	1168.10	1177.05
710.81	6.922	0.09264	155.96	1152.67	1163.18

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT #12 NODE #11)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02159	36.35	145.75	150.21
304.06	2.961	0.02583	43.48	174.32	179.66
354.91	3.456	0.03015	50.75	203.47	209.71
405.75	3.951	0.03446	58.02	232.62	239.75
456.59	4.446	0.03878	65.29	261.77	269.79
507.43	4.941	0.04310	72.56	290.92	299.83
558.28	5.436	0.04742	79.83	320.07	329.88
609.12	5.932	0.05174	87.10	349.22	359.92
659.96	6.427	0.05606	94.37	378.37	389.96
710.81	6.922	0.06038	101.64	407.52	420.00

FLOW ANGLES
ELEMENT #12: VANED DIFFUSER

IMPELLER SPEED[RPM] 95000

		INLET(NODE #10)			DISCHARGE(NODE #11)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.216	2.476	2.45	2.45	2.55	14.00	14.00	4.00
304.062	2.961	2.98	2.98	2.02	14.00	14.00	4.00
354.905	3.456	3.52	3.52	1.48	14.00	14.00	4.00
405.748	3.951	4.08	4.08	0.92	14.00	14.00	4.00
456.591	4.446	4.65	4.65	0.35	14.00	14.00	4.00
507.435	4.941	5.23	5.23	-0.23	14.00	14.00	4.00
558.278	5.436	5.83	5.83	-0.83	14.00	14.00	4.00
609.121	5.932	6.44	6.44	-1.44	14.00	14.00	4.00
659.964	6.427	7.07	7.07	-2.07	14.00	14.00	4.00
710.807	6.922	7.71	7.71	-2.71	14.00	14.00	4.00

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT #13 NODE #11)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	35.45	145.75	150.00
304.06	2.961	42.40	174.32	179.41
354.91	3.456	49.49	203.47	209.41
405.75	3.951	56.58	232.62	239.41
456.59	4.446	63.67	261.77	269.40
507.43	4.941	70.76	290.92	299.40
558.28	5.436	77.85	320.07	329.40
609.12	5.932	84.94	349.22	359.40
659.96	6.427	92.03	378.37	389.40
710.81	6.922	99.12	407.52	419.40

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT #13 NODE #12)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.00	0.00	150.00
304.06	2.961	0.00	0.00	179.41
354.91	3.456	0.00	0.00	209.41
405.75	3.951	0.00	0.00	239.41
456.59	4.446	0.00	0.00	269.40
507.43	4.941	0.00	0.00	299.40
558.28	5.436	0.00	0.00	329.40
609.12	5.932	0.00	0.00	359.40
659.96	6.427	0.00	0.00	389.40
710.81	6.922	0.00	0.00	419.40

FLOW ANGLES
ELEMENT #13: TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #11) BETA FLUID [deg]	INLET(NODE #11) ALPHA (RMS) [deg]	INLET(NODE #11) DEVIATION ANGLE [deg]	DISCHARGE(NODE #12) BETA FLUID [deg]	DISCHARGE(NODE #12) ALPHA (RMS) [deg]	DISCHARGE(NODE #12) DEVIATION ANGLE [deg]
254.216	2.476	2.45	2.45	2.55	14.00	14.00	4.00
304.062	2.961	2.98	2.98	2.02	14.00	14.00	4.00
354.905	3.456	3.52	3.52	1.48	14.00	14.00	4.00
405.748	3.951	4.08	4.08	0.92	14.00	14.00	4.00
456.591	4.446	4.65	4.65	0.35	14.00	14.00	4.00
507.435	4.941	5.23	5.23	-0.23	14.00	14.00	4.00
558.278	5.436	5.83	5.83	-0.83	14.00	14.00	4.00
609.121	5.932	6.44	6.44	-1.44	14.00	14.00	4.00
659.964	6.427	7.07	7.07	-2.07	14.00	14.00	4.00
710.807	6.922	7.71	7.71	-2.71	14.00	14.00	4.00

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT #14 NODE #12)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.00	0.00	35.45
304.06	2.961	0.00	0.00	42.40
354.91	3.456	0.00	0.00	49.49
405.75	3.951	0.00	0.00	56.58
456.59	4.446	0.00	0.00	63.67
507.43	4.941	0.00	0.00	70.76
558.28	5.436	0.00	0.00	77.85
609.12	5.932	0.00	0.00	84.94
659.96	6.427	0.00	0.00	92.03
710.81	6.922	0.00	0.00	99.12

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT #14 NODE #13)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.00	0.00	35.45
304.06	2.961	0.00	0.00	42.40
354.91	3.456	0.00	0.00	49.49
405.75	3.951	0.00	0.00	56.58
456.59	4.446	0.00	0.00	63.67
507.43	4.941	0.00	0.00	70.76
558.28	5.436	0.00	0.00	77.85
609.12	5.932	0.00	0.00	84.94
659.96	6.427	0.00	0.00	92.03
710.81	6.922	0.00	0.00	99.12

FLOW ANGLES
ELEMENT #14: DOWNCOMER

IMPELLER SPEED[RPM] = 95000

		INLET(NODE #12)			DISCHARGE(NODE #13)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.216	2.476	2.45	90.00	2.55	14.00	90.00	4.00
304.062	2.961	2.98	90.00	2.02	14.00	90.00	4.00
354.905	3.456	3.52	90.00	1.48	14.00	90.00	4.00
405.748	3.951	4.08	90.00	0.92	14.00	90.00	4.00
456.591	4.446	4.65	90.00	0.35	14.00	90.00	4.00
507.435	4.941	5.23	90.00	-0.23	14.00	90.00	4.00
558.278	5.436	5.83	90.00	-0.83	14.00	90.00	4.00
609.121	5.932	6.44	90.00	-1.44	14.00	90.00	4.00
659.964	6.427	7.07	90.00	-2.07	14.00	90.00	4.00
710.807	6.922	7.71	90.00	-2.71	14.00	90.00	4.00

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT #15 NODE #13)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	35.45	0.00	35.45
304.06	2.961	42.40	0.00	42.40
354.91	3.456	49.49	0.00	49.49
405.75	3.951	56.58	0.00	56.58
456.59	4.446	63.67	0.00	63.67
507.43	4.941	70.76	0.00	70.76
558.28	5.436	77.85	0.00	77.85
609.12	5.932	84.94	0.00	84.94
659.96	6.427	92.03	0.00	92.03
710.81	6.922	99.12	0.00	99.12

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT #15 NODE #14)
IMPELLER SPEED[RPM] . 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.00	0.00	35.45
304.06	2.961	0.00	0.00	42.40
354.91	3.456	0.00	0.00	49.49
405.75	3.951	0.00	0.00	56.58
456.59	4.446	0.00	0.00	63.67
507.43	4.941	0.00	0.00	70.76
558.28	5.436	0.00	0.00	77.85
609.12	5.932	0.00	0.00	84.94
659.96	6.427	0.00	0.00	92.03
710.81	6.922	0.00	0.00	99.12

FLOW ANGLES
ELEMENT #15: TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #13) BETA FLUID [deg]	INLET(NODE #13) ALPHA (RMS) [deg]	INLET(NODE #13) DEVIATION ANGLE [deg]	DISCHARGE(NODE #14) BETA FLUID [deg]	DISCHARGE(NODE #14) ALPHA (RMS) [deg]	DISCHARGE(NODE #14) DEVIATION ANGLE [deg]
254.216	2.476	2.45	90.00	2.55	14.00	90.00	4.00
304.062	2.961	2.98	90.00	2.02	14.00	90.00	4.00
354.905	3.456	3.52	90.00	1.48	14.00	90.00	4.00
405.748	3.951	4.08	90.00	0.92	14.00	90.00	4.00
456.591	4.446	4.65	90.00	0.35	14.00	90.00	4.00
507.435	4.941	5.23	90.00	-0.23	14.00	90.00	4.00
558.278	5.436	5.83	90.00	-0.83	14.00	90.00	4.00
609.121	5.932	6.44	90.00	-1.44	14.00	90.00	4.00
659.964	6.427	7.07	90.00	-2.07	14.00	90.00	4.00
710.807	6.922	7.71	90.00	-2.71	14.00	90.00	4.00

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT #16 NODE #14)
IMPELLER SPEED[RPM] 95000
URMS[ft/s] = 662.35

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
293.20	2.855	0.03909	65.80	0.00	65.80	150.10
343.00	3.340	0.04572	76.97	0.00	76.97	175.59
393.78	3.835	0.05249	88.37	0.00	88.37	201.58
444.53	4.329	0.05926	99.76	0.00	99.76	227.56
495.26	4.823	0.06602	111.14	0.00	111.14	253.54
545.97	5.317	0.07278	122.52	0.00	122.52	279.50
596.66	5.810	0.07954	133.90	0.00	133.90	305.45
647.34	6.304	0.08629	145.27	0.00	145.27	331.39
697.99	6.797	0.09305	156.64	0.00	156.64	357.32
748.63	7.290	0.09980	168.00	0.00	168.00	383.24

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT #16 NODE #15)
IMPELLER SPEED[RPM] = 95000
URMS[ft/s] 1683.45

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
293.20	2.855	0.03535	59.51	1402.01	1403.28	97.75
343.00	3.340	0.04135	69.61	1383.20	1384.96	114.35
393.78	3.835	0.04747	79.92	1364.42	1366.76	131.28
444.53	4.329	0.05359	90.22	1346.01	1349.03	148.20
495.26	4.823	0.05971	100.51	1327.94	1331.75	165.11
545.97	5.317	0.06582	110.80	1310.20	1314.88	182.02
596.66	5.810	0.07193	121.09	1292.77	1298.43	198.92
647.34	6.304	0.07804	131.38	1275.61	1282.37	215.81
697.99	6.797	0.08415	141.66	1258.73	1266.68	232.70
748.63	7.290	0.09025	151.93	1242.10	1251.36	249.58

FLOW ANGLES
ELEMENT #16: IMPELLER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #14) BETA FLUID [deg]	INLET(NODE #14) ALPHA (RMS) [deg]	INLET(NODE #14) DEVIATION ANGLE [deg]	DISCHARGE(NODE #15) BETA FLUID [deg]	DISCHARGE(NODE #15) ALPHA (RMS) [deg]	DISCHARGE(NODE #15) DEVIATION ANGLE [deg]
293.204	2.855	5.67	90.00	20.33	11.94	2.43	25.56
343.002	3.340	6.63	90.00	19.37	13.05	2.88	24.45
393.775	3.835	7.60	90.00	18.40	14.06	3.35	23.44
444.527	4.329	8.56	90.00	17.44	14.97	3.83	22.53
495.258	4.823	9.53	90.00	16.47	15.79	4.33	21.71
545.970	5.317	10.48	90.00	15.52	16.53	4.83	20.97
596.662	5.810	11.43	90.00	14.57	17.22	5.35	20.28
647.336	6.304	12.37	90.00	13.63	17.86	5.88	19.64
697.991	6.797	13.31	90.00	12.69	18.44	6.42	19.06
748.628	7.290	14.23	90.00	11.77	19.00	6.97	18.50

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT #18 NODE #15)
IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02981	50.19	1402.01	1402.91
304.06	2.961	0.03566	60.03	1383.20	1384.51
354.91	3.456	0.04162	70.06	1364.42	1366.22
405.75	3.951	0.04758	80.10	1346.01	1348.39
456.59	4.446	0.05354	90.14	1327.94	1331.00
507.43	4.941	0.05950	100.17	1310.20	1314.03
558.28	5.436	0.06547	110.21	1292.77	1297.46
609.12	5.932	0.07143	120.25	1275.61	1281.27
659.96	6.427	0.07739	130.28	1258.73	1265.46
710.81	6.922	0.08335	140.32	1242.10	1250.00

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT #18 NODE #16)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02775	46.71	1304.90	1305.74
304.06	2.961	0.03319	55.87	1287.39	1288.61
354.91	3.456	0.03874	65.21	1269.91	1271.59
405.75	3.951	0.04428	74.55	1252.77	1254.99
456.59	4.446	0.04983	83.89	1235.96	1238.81
507.43	4.941	0.05538	93.23	1219.45	1223.01
558.28	5.436	0.06093	102.58	1203.22	1207.59
609.12	5.932	0.06648	111.92	1187.26	1192.52
659.96	6.427	0.07203	121.26	1171.54	1177.80
710.81	6.922	0.07758	130.60	1156.06	1163.42

FLOW ANGLES
ELEMENT #18: VANLESS DIFFUSER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #15) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE #16) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.216	2.476	2.05	2.05	-2.05	2.05	2.05	-2.05
304.062	2.961	2.48	2.48	-2.48	2.48	2.48	-2.48
354.905	3.456	2.94	2.94	-2.94	2.94	2.94	-2.94
405.748	3.951	3.41	3.41	-3.41	3.41	3.41	-3.41
456.591	4.446	3.88	3.88	-3.88	3.88	3.88	-3.88
507.435	4.941	4.37	4.37	-4.37	4.37	4.37	-4.37
558.278	5.436	4.87	4.87	-4.87	4.87	4.87	-4.87
609.121	5.932	5.39	5.39	-5.39	5.39	5.39	-5.39
659.964	6.427	5.91	5.91	-5.91	5.91	5.91	-5.91
710.807	6.922	6.45	6.45	-6.45	6.45	6.45	-6.45

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT #19 NODE #16)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.03313	55.78	1304.90	1306.10
304.06	2.961	0.03963	66.72	1287.39	1289.12
354.91	3.456	0.04626	77.87	1269.91	1272.30
405.75	3.951	0.05288	89.03	1252.77	1255.94
456.59	4.446	0.05951	100.18	1235.96	1240.02
507.43	4.941	0.06614	111.34	1219.45	1224.53
558.28	5.436	0.07276	122.49	1203.22	1209.44
609.12	5.932	0.07939	133.65	1187.26	1194.76
659.96	6.427	0.08602	144.81	1171.54	1180.46
710.81	6.922	0.09264	155.96	1156.06	1166.54

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT #19 NODE #17)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	0.02159	36.35	145.75	150.21
304.06	2.961	0.02583	43.48	174.32	179.66
354.91	3.456	0.03015	50.75	203.47	209.71
405.75	3.951	0.03446	58.02	232.62	239.75
456.59	4.446	0.03878	65.29	261.77	269.79
507.43	4.941	0.04310	72.56	290.92	299.83
558.28	5.436	0.04742	79.83	320.07	329.88
609.12	5.932	0.05174	87.10	349.22	359.92
659.96	6.427	0.05606	94.37	378.37	389.96
710.81	6.922	0.06038	101.64	407.52	420.00

FLOW ANGLES
ELEMENT #19: VANED DIFFUSER

IMPELLER SPEED[RPM] = 95000

		INLET(NODE #16)			DISCHARGE(NODE #17)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.216	2.476	2.45	2.45	2.55	14.00	14.00	4.00
304.062	2.961	2.97	2.97	2.03	14.00	14.00	4.00
354.905	3.456	3.51	3.51	1.49	14.00	14.00	4.00
405.748	3.951	4.06	4.06	0.94	14.00	14.00	4.00
456.591	4.446	4.63	4.63	0.37	14.00	14.00	4.00
507.435	4.941	5.22	5.22	-0.22	14.00	14.00	4.00
558.278	5.436	5.81	5.81	-0.81	14.00	14.00	4.00
609.121	5.932	6.42	6.42	-1.42	14.00	14.00	4.00
659.964	6.427	7.05	7.05	-2.05	14.00	14.00	4.00
710.807	6.922	7.68	7.68	-2.68	14.00	14.00	4.00

FLUID VELOCITIES
1-DISC. VOLUTE INLET
(ELEMENT #20 NODE #17)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	36.35	145.75	150.21
304.06	2.961	43.48	174.32	179.66
354.91	3.456	50.75	203.47	209.71
405.75	3.951	58.02	232.62	239.75
456.59	4.446	65.29	261.77	269.79
507.43	4.941	72.56	290.92	299.83
558.28	5.436	79.83	320.07	329.88
609.12	5.932	87.10	349.22	359.92
659.96	6.427	94.37	378.37	389.96
710.81	6.922	101.64	407.52	420.00

FLUID VELOCITIES
1-DISC. VOLUTE DISCHARGE
(ELEMENT #20 NODE #18)
IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
254.22	2.476	21.84	0.00	21.84
304.06	2.961	26.12	0.00	26.12
354.91	3.456	30.49	0.00	30.49
405.75	3.951	34.86	0.00	34.86
456.59	4.446	39.23	0.00	39.23
507.43	4.941	43.59	0.00	43.59
558.28	5.436	47.96	0.00	47.96
609.12	5.932	52.33	0.00	52.33
659.96	6.427	56.70	0.00	56.70
710.81	6.922	61.07	0.00	61.07

FLOW ANGLES
ELEMENT #20: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] 95000

		INLET(NODE #17)			DISCHARGE(NODE #18)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
254.216	2.476	14.00	14.00	2.55	90.00	90.00	4.00
304.062	2.961	14.00	14.00	2.03	90.00	90.00	4.00
354.905	3.456	14.00	14.00	1.49	90.00	90.00	4.00
405.748	3.951	14.00	14.00	0.94	90.00	90.00	4.00
456.591	4.446	14.00	14.00	0.37	90.00	90.00	4.00
507.435	4.941	14.00	14.00	-0.22	90.00	90.00	4.00
558.278	5.436	14.00	14.00	-0.81	90.00	90.00	4.00
609.121	5.932	14.00	14.00	-1.42	90.00	90.00	4.00
659.964	6.427	14.00	14.00	-2.05	90.00	90.00	4.00
710.807	6.922	14.00	14.00	-2.68	90.00	90.00	4.00

NODAL PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) TOTAL HEAD [ft]	TEMP. [R]	NPSH AVAIL. [ft]	VAPOR PRES [PSIA]	STATIC PRES [PSIA]	DISCHARGE(NODE # 2) TOTAL HEAD [ft]	TEMP. [R]	STATIC PRES [PSIA]
254.98	2.483	2339.6	40.0	1023.2	25.089	69.9	9501.5	40.0	194.5
304.98	2.970	2339.6	40.0	1147.2	25.089	69.5	8877.3	40.0	190.9
355.97	3.466	2339.6	40.0	1267.4	25.089	68.9	8225.5	40.0	185.1
406.97	3.963	2339.6	40.0	1381.2	25.089	68.3	7558.7	40.0	177.2
457.96	4.460	2339.6	40.0	1488.6	25.089	67.6	6876.8	40.0	167.2
508.96	4.956	2339.6	40.0	1589.7	25.089	66.7	6179.8	40.0	155.0
559.96	5.453	2339.6	40.0	1684.3	25.089	65.8	5467.9	40.0	140.6
610.95	5.949	2339.6	40.0	1772.6	25.089	64.9	4741.0	40.0	124.2
661.95	6.446	2339.6	40.0	1854.5	25.089	63.8	3999.3	40.0	105.6
712.94	6.943	2339.6	40.0	1930.0	25.089	62.6	3242.7	40.0	84.8

ELEMENT LOSSES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.98	2.483	2029892.	0.01494	0.00030	0.00454	0.01978
304.98	2.970	2427909.	0.01354	0.00043	0.00377	0.01773
355.97	3.466	2833887.	0.01217	0.00058	0.00306	0.01581
406.97	3.963	3239865.	0.01088	0.00076	0.00242	0.01406
457.96	4.460	3645844.	0.00966	0.00096	0.00186	0.01248
508.96	4.956	4051822.	0.00851	0.00119	0.00137	0.01107
559.96	5.453	4457801.	0.00744	0.00143	0.00096	0.00983
610.95	5.949	4863779.	0.00644	0.00170	0.00062	0.00877
661.95	6.446	5269758.	0.00551	0.00200	0.00036	0.00786
712.94	6.943	5675735.	0.00465	0.00232	0.00017	0.00713

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
254.98	2.48	2029892.	0.0813	0.1011	0.8043	7161.9	124.5	0.0
304.98	2.97	2427909.	0.0742	0.0920	0.8072	6537.7	121.4	0.0
355.97	3.47	2833887.	0.0668	0.0826	0.8087	5886.0	116.2	0.0
406.97	3.96	3239865.	0.0593	0.0733	0.8082	5219.1	108.9	0.0
457.96	4.46	3645844.	0.0515	0.0640	0.8049	4537.2	99.6	0.0
508.96	4.96	4051822.	0.0436	0.0547	0.7975	3840.2	88.2	0.0
559.96	5.45	4457801.	0.0355	0.0453	0.7831	3128.3	74.8	0.0
610.95	5.95	4863779.	0.0273	0.0360	0.7567	2401.4	59.3	0.0
661.95	6.45	5269758.	0.0188	0.0267	0.7055	1659.7	41.8	0.0
712.94	6.94	5675735.	0.0103	0.0174	0.5897	903.1	22.2	0.0

ELEMENT LOSSES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
300.64	2.928	1372893.	0.00044	0.00037	0.00011	0.00093
350.88	3.417	1602315.	0.00061	0.00051	0.00001	0.00113
402.18	3.916	1836608.	0.00081	0.00066	0.00000	0.00147
453.56	4.417	2071239.	0.00104	0.00084	0.00000	0.00188
505.02	4.918	2306208.	0.00129	0.00104	0.00001	0.00234
556.55	5.420	2541507.	0.00157	0.00126	0.00002	0.00285
608.14	5.922	2777128.	0.00188	0.00151	0.00004	0.00343
659.81	6.425	3013064.	0.00222	0.00177	0.00007	0.00406
711.54	6.929	3249305.	0.00258	0.00206	0.00010	0.00474
763.34	7.433	3485840.	0.00297	0.00237	0.00014	0.00547

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 3: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP. DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.008		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 3:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
300.64	2.928	0.036244	0.44464	0.02894
350.88	3.417	0.042300	0.44701	0.02480
402.18	3.916	0.048486	0.45003	0.02164
453.56	4.417	0.054680	0.45377	0.01918
505.02	4.918	0.060883	0.45823	0.01723
556.55	5.420	0.067094	0.46339	0.01563
608.14	5.922	0.073315	0.46925	0.01431
659.81	6.425	0.079543	0.47577	0.01319
711.54	6.929	0.085780	0.48294	0.01223
763.34	7.433	0.092024	0.49074	0.01140

ELEMENT LOSSES
ELEMENT # 4:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.60	2.479	16894934.	0.00000	0.06950	0.00000	0.06950
304.52	2.965	16671587.	0.00000	0.05583	0.00000	0.05583
355.44	3.461	16449289.	0.00000	0.04595	0.00000	0.04595
406.36	3.957	16232195.	0.00000	0.03862	0.00000	0.03862
457.28	4.453	16020048.	0.00000	0.03299	0.00000	0.03299
508.20	4.949	15812622.	0.00000	0.02855	0.00000	0.02855
559.12	5.445	15609729.	0.00000	0.02496	0.00000	0.02496
610.04	5.940	15411213.	0.00000	0.02202	0.00000	0.02202
660.96	6.436	15216933.	0.00000	0.01956	0.00000	0.01956
711.88	6.932	15026774.	0.00000	0.01749	0.00000	0.01749

ELEMENT LOSSES
ELEMENT # 5:VANED DIFFUSER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.60	2.479	2362973.	0.02332	0.00507	0.09475	0.12314
304.52	2.965	2826301.	0.01436	0.00725	0.08714	0.10876
355.44	3.461	3298896.	0.00747	0.00988	0.07962	0.09697
406.36	3.957	3771490.	0.00282	0.01291	0.07237	0.08810
457.28	4.453	4244085.	0.00039	0.01634	0.06542	0.08215
508.20	4.949	4716679.	0.00018	0.02017	0.05877	0.07912
559.12	5.445	5189274.	0.00217	0.02441	0.05244	0.07903
610.04	5.940	5661869.	0.00636	0.02905	0.04646	0.08186
660.96	6.436	6134463.	0.01272	0.03409	0.04082	0.08763
711.88	6.932	6607058.	0.02126	0.03954	0.03555	0.09635

ELEMENT LOSSES
ELEMENT # 6:TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.60	2.479	3405014.	0.00000	0.00136	0.00000	0.00136
304.52	2.965	4072664.	0.00000	0.00194	0.00000	0.00194
355.44	3.461	4753667.	0.00000	0.00264	0.00000	0.00264
406.36	3.957	5434669.	0.00000	0.00345	0.00000	0.00345
457.28	4.453	6115673.	0.00000	0.00437	0.00000	0.00437
508.20	4.949	6796675.	0.00000	0.00539	0.00000	0.00539
559.12	5.445	7477679.	0.00000	0.00652	0.00000	0.00652
610.04	5.940	8158681.	0.00000	0.00776	0.00000	0.00776
660.96	6.436	8839684.	0.00000	0.00911	0.00000	0.00911
711.88	6.932	9520687.	0.00000	0.01057	0.00000	0.01057

ELEMENT LOSSES
ELEMENT # 7:DOWNCOMER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.60	2.479	1137693.	0.00000	0.00003	0.00000	0.00003
304.52	2.965	1360770.	0.00000	0.00004	0.00000	0.00004
355.44	3.461	1588309.	0.00000	0.00005	0.00000	0.00005
406.36	3.957	1815847.	0.00000	0.00006	0.00000	0.00006
457.28	4.453	2043386.	0.00000	0.00008	0.00000	0.00008
508.20	4.949	2270924.	0.00000	0.00010	0.00000	0.00010
559.12	5.445	2498463.	0.00000	0.00012	0.00000	0.00012
610.04	5.940	2726002.	0.00000	0.00014	0.00000	0.00014
660.96	6.436	2953541.	0.00000	0.00017	0.00000	0.00017
711.88	6.932	3181079.	0.00000	0.00020	0.00000	0.00020

ELEMENT LOSSES
ELEMENT # 8:TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.60	2.479	804753.	0.00000	0.00007	0.00000	0.00007
304.52	2.965	962548.	0.00000	0.00011	0.00000	0.00011
355.44	3.461	1123499.	0.00000	0.00014	0.00000	0.00014
406.36	3.957	1284449.	0.00000	0.00019	0.00000	0.00019
457.28	4.453	1445400.	0.00000	0.00024	0.00000	0.00024
508.20	4.949	1606350.	0.00000	0.00029	0.00000	0.00029
559.12	5.445	1767301.	0.00000	0.00036	0.00000	0.00036
610.04	5.940	1928252.	0.00000	0.00042	0.00000	0.00042
660.96	6.436	2089202.	0.00000	0.00050	0.00000	0.00050
711.88	6.932	2250153.	0.00000	0.00058	0.00000	0.00058

ELEMENT LOSSES
ELEMENT # 9:IMPELLER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
304.08	2.961	1388595.	0.01445	0.00038	0.00208	0.01691
353.93	3.447	1616262.	0.01321	0.00052	0.00176	0.01548
404.76	3.941	1848356.	0.01200	0.00067	0.00148	0.01415
455.55	4.436	2080328.	0.01085	0.00085	0.00123	0.01293
506.33	4.931	2312181.	0.00976	0.00105	0.00102	0.01182
557.07	5.425	2543920.	0.00873	0.00126	0.00084	0.01083
607.80	5.919	2775548.	0.00775	0.00150	0.00068	0.00994
658.49	6.412	3007068.	0.00684	0.00176	0.00055	0.00915
709.17	6.906	3238481.	0.00598	0.00204	0.00044	0.00847
759.82	7.399	3469791.	0.00518	0.00235	0.00035	0.00787

BOUNDARY/OPERATING CONDITIONS
ELEMENT #10: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP. DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.007		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #10: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
304.08	2.961	0.036658	0.48183	0.02862
353.93	3.447	0.042668	0.48119	0.02459
404.76	3.941	0.048796	0.48026	0.02150
455.55	4.436	0.054920	0.47908	0.01910
506.33	4.931	0.061040	0.47764	0.01719
557.07	5.425	0.067158	0.47596	0.01562
607.80	5.919	0.073273	0.47404	0.01432
658.49	6.412	0.079385	0.47189	0.01321
709.17	6.906	0.085494	0.46952	0.01227
759.82	7.399	0.091601	0.46692	0.01145

ELEMENT LOSSES
ELEMENT #11: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	16879138.	0.00000	0.06941	0.00000	0.06941
304.06	2.961	16657827.	0.00000	0.05578	0.00000	0.05578
354.91	3.456	16437910.	0.00000	0.04592	0.00000	0.04592
405.75	3.951	16223528.	0.00000	0.03861	0.00000	0.03861
456.59	4.446	16014401.	0.00000	0.03301	0.00000	0.03301
507.43	4.941	15810284.	0.00000	0.02858	0.00000	0.02858
558.28	5.436	15610973.	0.00000	0.02501	0.00000	0.02501
609.12	5.932	15416289.	0.00000	0.02207	0.00000	0.02207
659.96	6.427	15226067.	0.00000	0.01963	0.00000	0.01963
710.81	6.922	15040179.	0.00000	0.01756	0.00000	0.01756

ELEMENT LOSSES
ELEMENT #12: VANED DIFFUSER

IMPELLER SPEED[RPM]   95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	2359429.	0.02330	0.00506	0.09477	0.12313
304.06	2.961	2822061.	0.01437	0.00723	0.08717	0.10877
354.91	3.456	3293948.	0.00749	0.00985	0.07966	0.09700
405.75	3.951	3765832.	0.00284	0.01287	0.07242	0.08813
456.59	4.446	4237718.	0.00040	0.01629	0.06548	0.08217
507.43	4.941	4709604.	0.00017	0.02011	0.05884	0.07913
558.28	5.436	5181491.	0.00213	0.02434	0.05254	0.07900
609.12	5.932	5653376.	0.00626	0.02896	0.04657	0.08178
659.96	6.427	6125262.	0.01255	0.03399	0.04095	0.08749
710.81	6.922	6597147.	0.02101	0.03943	0.03570	0.09613

ELEMENT LOSSES
ELEMENT #13: TURNING CHANNEL

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	3399907.	0.00000	0.00135	0.00000	0.00135
304.06	2.961	4066555.	0.00000	0.00193	0.00000	0.00193
354.91	3.456	4746537.	0.00000	0.00263	0.00000	0.00263
405.75	3.951	5426516.	0.00000	0.00344	0.00000	0.00344
456.59	4.446	6106498.	0.00000	0.00435	0.00000	0.00435
507.43	4.941	6786481.	0.00000	0.00537	0.00000	0.00537
558.28	5.436	7466462.	0.00000	0.00650	0.00000	0.00650
609.12	5.932	8146444.	0.00000	0.00774	0.00000	0.00774
659.96	6.427	8826425.	0.00000	0.00909	0.00000	0.00909
710.81	6.922	9506406.	0.00000	0.01054	0.00000	0.01054

ELEMENT LOSSES
ELEMENT #14: DOWNCOMER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	1135987.	0.00000	0.00003	0.00000	0.00003
304.06	2.961	1358729.	0.00000	0.00004	0.00000	0.00004
354.91	3.456	1585926.	0.00000	0.00005	0.00000	0.00005
405.75	3.951	1813123.	0.00000	0.00006	0.00000	0.00006
456.59	4.446	2040320.	0.00000	0.00008	0.00000	0.00008
507.43	4.941	2267518.	0.00000	0.00010	0.00000	0.00010
558.28	5.436	2494715.	0.00000	0.00012	0.00000	0.00012
609.12	5.932	2721913.	0.00000	0.00014	0.00000	0.00014
659.96	6.427	2949110.	0.00000	0.00017	0.00000	0.00017
710.81	6.922	3176307.	0.00000	0.00019	0.00000	0.00019

ELEMENT LOSSES
ELEMENT #15: TURNING CHANNEL

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	803546.	0.00000	0.00007	0.00000	0.00007
304.06	2.961	961104.	0.00000	0.00011	0.00000	0.00011
354.91	3.456	1121813.	0.00000	0.00014	0.00000	0.00014
405.75	3.951	1282522.	0.00000	0.00019	0.00000	0.00019
456.59	4.446	1443232.	0.00000	0.00024	0.00000	0.00024
507.43	4.941	1603941.	0.00000	0.00029	0.00000	0.00029
558.28	5.436	1764650.	0.00000	0.00035	0.00000	0.00035
609.12	5.932	1925359.	0.00000	0.00042	0.00000	0.00042
659.96	6.427	2086068.	0.00000	0.00049	0.00000	0.00049
710.81	6.922	2246778.	0.00000	0.00057	0.00000	0.00057

ELEMENT LOSSES
ELEMENT #16: IMPELLER

IMPELLER SPEED[RPM] = 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
293.20	2.855	1338937.	0.01472	0.00036	0.00216	0.01724
343.00	3.340	1566347.	0.01347	0.00048	0.00183	0.01579
393.78	3.835	1798206.	0.01225	0.00064	0.00154	0.01443
444.53	4.329	2029969.	0.01109	0.00081	0.00128	0.01318
495.26	4.823	2261637.	0.00999	0.00100	0.00106	0.01206
545.97	5.317	2493215.	0.00895	0.00122	0.00088	0.01104
596.66	5.810	2724705.	0.00796	0.00145	0.00072	0.01013
647.34	6.304	2956109.	0.00703	0.00171	0.00058	0.00932
697.99	6.797	3187429.	0.00616	0.00198	0.00047	0.00861
748.63	7.290	3418667.	0.00535	0.00228	0.00037	0.00800

ELEMENT LOSSES
ELEMENT #18: VANLESS DIFFUSER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	16929082.	0.00000	0.07003	0.00000	0.07003
304.06	2.961	16706974.	0.00000	0.05627	0.00000	0.05627
354.91	3.456	16486279.	0.00000	0.04633	0.00000	0.04633
405.75	3.951	16271162.	0.00000	0.03896	0.00000	0.03896
456.59	4.446	16061331.	0.00000	0.03330	0.00000	0.03330
507.43	4.941	15856533.	0.00000	0.02883	0.00000	0.02883
558.28	5.436	15656567.	0.00000	0.02522	0.00000	0.02522
609.12	5.932	15461238.	0.00000	0.02226	0.00000	0.02226
659.96	6.427	15270391.	0.00000	0.01980	0.00000	0.01980
710.81	6.922	15083885.	0.00000	0.01772	0.00000	0.01772

BOUNDARY/OPERATING CONDITIONS
ELEMENT #17: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			1.900		
IMP. INLET HUB DIAMETER [in]			1.220		
IMP. DISC. TIP DIAMETER [in]			4.058		
IMP. DISC. HUB DIAMETER [in]			4.058		
FRONT WEAR RING LEAKAGE COEF.			0.004		
FRONT WEAR RING CLEARANCE [in]			0.006		
FRONT WEAR RING DIAMETER [in]			1.230		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #17: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
293.20	2.855	0.035347	0.37966	0.02968
343.00	3.340	0.041351	0.37920	0.02537
393.78	3.835	0.047472	0.37851	0.02210
444.53	4.329	0.053590	0.37763	0.01957
495.26	4.823	0.059706	0.37654	0.01757
545.97	5.317	0.065820	0.37525	0.01594
596.66	5.810	0.071931	0.37379	0.01458
647.34	6.304	0.078040	0.37213	0.01344
697.99	6.797	0.084147	0.37030	0.01247
748.63	7.290	0.090251	0.36830	0.01162

ELEMENT LOSSES
ELEMENT #19: VANED DIFFUSER

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	2359429.	0.02357	0.00506	0.09488	0.12351
304.06	2.961	2822061.	0.01458	0.00723	0.08729	0.10910
354.91	3.456	3293948.	0.00764	0.00985	0.07980	0.09728
405.75	3.951	3765832.	0.00293	0.01287	0.07257	0.08837
456.59	4.446	4237718.	0.00044	0.01629	0.06564	0.08237
507.43	4.941	4709604.	0.00015	0.02011	0.05901	0.07928
558.28	5.436	5181491.	0.00205	0.02434	0.05271	0.07910
609.12	5.932	5653376.	0.00613	0.02896	0.04674	0.08183
659.96	6.427	6125262.	0.01238	0.03399	0.04113	0.08749
710.81	6.922	6597147.	0.02078	0.03943	0.03587	0.09608

ELEMENT LOSSES
ELEMENT #20: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] 95000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
254.22	2.476	2091816.	0.00177	0.00000	0.04264	0.04442
304.06	2.961	2501975.	0.00253	0.00000	0.04264	0.04518
354.91	3.456	2920339.	0.00345	0.00001	0.04264	0.04610
405.75	3.951	3338701.	0.00451	0.00001	0.04264	0.04716
456.59	4.446	3757065.	0.00571	0.00001	0.04264	0.04837
507.43	4.941	4175429.	0.00706	0.00001	0.04264	0.04971
558.28	5.436	4593792.	0.00854	0.00001	0.04264	0.05120
609.12	5.932	5012155.	0.01017	0.00002	0.04264	0.05283
659.96	6.427	5430519.	0.01194	0.00002	0.04264	0.05460
710.81	6.922	5848882.	0.01385	0.00002	0.04264	0.05651

XLR-134 Turbopump

The XLR-134 Turbopump is used for low thrust cryogenic engine applications, developed by Aerojet Propulsion Division. The XLR134 fuel pump spool #1 CPAC model consists of 3 similar stages. Each stage contains an identical impeller element of tip diameter 1.873 inches. The first stage **impeller** is prefaced with an **inducer**, and followed by a **vaneless diffuser**, and crossover assembly. The crossover assembly is modeled as a va**ned diffuser**, (upcomer), a **turning channel**, and a **downcomer**. The second stage **impeller** follows the first stage downcomer. The second stage is modeled identically as the first stage, without an inducer element. Following the second stage crossover assembly is the third stage **impeller** element, followed by a **vaneless diffuser**, a **single discharge volute**, and a **single discharge exit diffuser**.

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET TO NODE	DISC. TO NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	LEAKAGE w/ FS FWR	3	2
4	VANLESS DIFFUSER	3	4
5	VANED DIFFUSER	4	5
6	TURNING CHANNEL	5	6
7	DOWNCOMER	6	7
8	IMPELLER	7	8
9	LEAKAGE w/ FS FWR	8	7
10	VANLESS DIFFUSER	8	9
11	VANED DIFFUSER	9	10
12	TURNING CHANNEL	10	11
13	DOWNCOMER	11	12
14	LEAKAGE w/ RS RWR	12	8
15	IMPELLER	12	13
16	LEAKAGE w/ FS FWR	13	12
17	VANLESS DIFFUSER	13	14
18	1-DISC. VOLUTE	14	15
19	1-DISC. EXIT DIFF.	15	16

INLET FLUID PROPERTIES

FLUID DENSITY [lb/ft^3] 4.366
FLUID VISCOSITY [ft^2/s] 0.00000194

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 74000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
9.28	0.09	0.0147	1.3861	3.6788	0.3768	16421.0	494.1	37.8
11.12	0.11	0.0173	1.5072	3.3802	0.4459	17809.1	535.7	37.8
12.96	0.13	0.0199	1.5821	3.1687	0.4993	18675.0	561.5	37.8
14.79	0.14	0.0225	1.6373	3.0135	0.5433	19318.7	580.6	37.8
17.08	0.17	0.0257	1.6871	2.8720	0.5874	19907.6	597.8	37.8
18.46	0.18	0.0277	1.7095	2.8059	0.6092	20176.3	605.6	37.8
20.29	0.20	0.0303	1.7318	2.7345	0.6333	20450.9	613.4	37.8
22.13	0.21	0.0329	1.7469	2.6769	0.6526	20646.7	618.8	37.8
23.96	0.23	0.0355	1.7560	2.6296	0.6678	20905.0	626.1	37.8
25.80	0.25	0.0381	1.7596	2.5898	0.6794	21181.7	633.8	37.8

GEOMETRY
ELEMENT #1: INDUCER

INLET TIP DIAMETER [in]	0.643
INLET HUB DIAMETER [in]	0.322
INLET PASSAGE WIDTH [in]	0.1605
INLET BLADE ANGLE [deg]	7.2
NUMBER OF INLET BLADES	4
INLET NORMAL THICKNESS [in]	0.01
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	0.643
DISCH. HUB DIAMETER [in]	0.399
DISCH. PASSAGE WIDTH [in]	0.122
DISCH. BLADE ANGLE [deg]	12.3
NUMBER OF DISCH. BLADES	4
DISCH. NORMAL THICKNESS [in]	0.01
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	1.5
SURFACE ROUGHNESS [in]	0.0001

GEOMETRY
ELEMENTS #2,8,15: IMPELLER

INLET TIP DIAMETER [in]	0.643
INLET HUB DIAMETER [in]	0.399
INLET PASSAGE WIDTH [in]	0.122
INLET BLADE ANGLE [deg]	20.299999
NUMBER OF INLET BLADES	8
INLET NORMAL THICKNESS [in]	0.01
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	1.873
DISCH. HUB DIAMETER [in]	1.873
DISCH. PASSAGE WIDTH [in]	0.064
DISCH. BLADE ANGLE [deg]	40
NUMBER OF DISCH. BLADES	8
DISCH. NORMAL THICKNESS [in]	0.01
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	0.25
SURFACE ROUGHNESS [in]	0.0001

BOUNDARY/OPERATING CONDITIONS
ELEMENTS # 2,8,15: IMPELLER

MAX. EFFICIENCY HEAD COEF:				0.450		
MAX. EFF. IMPELLER DISCHARGE FLOW COEF:				0.050		
IMPELLER CLEARANCE TORQUE COEF:				0.010		
IMPELLER BLADE LOADING COEF (AA)				-6328.568		
IMPELLER BLADE LOADING COEF (BB)				3143.020		
IMPELLER BLADE LOADING COEF (CC)				-370.300		
IMPELLER FRONT SHROUD CLEARANCE [in]:				0.0500		
IMPELLER REAR SHROUD CLEARANCE [in]:				0.0500		
INLET PRESSURE [PSIA]:				0.00		
INLET BYPASS FLOW RATE [%]·				0.00		(-8.11 For Element #8)
INLET CU [ft/s]	93.14	77.18	61.23	45.28	25.40	
	13.37	-2.59	-18.54	-34.50	-50.45	
INLET TEMP. [R]:	37.80	37.80	37.80	37.80	37.80	
	37.80	37.80	37.80	37.80	37.80	

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 3: LEAKAGE w/ FS FWR

IMP INLET TIP DIAMETER [in]			0.643		
IMP INLET HUB DIAMETER [in]			0.399		
IMP DISC. TIP DIAMETER [in]			1.873		
IMP DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 3:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
9.19	0.089	0.014724	0.01145	0.11198
10.81	0.104	0.017310	0.01157	0.09525
12.42	0.120	0.019900	0.01172	0.08285
14.04	0.136	0.022494	0.01189	0.07330
16.06	0.155	0.025732	0.01215	0.06407
17.29	0.167	0.027695	0.01232	0.05953
18.92	0.183	0.030301	0.01256	0.05441
20.54	0.199	0.032910	0.01283	0.05010
22.18	0.214	0.035523	0.01311	0.04641
23.81	0.230	0.038139	0.01342	0.04323

GEOMETRY
ELEMENTS #4,10,17: VANLESS DIFFUSER

INLET TIP DIAMETER [in]	1.873
INLET HUB DIAMETER [in]	1.873
INLET PASSAGE WIDTH [in]	0.064
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	2.06
DISCH. HUB DIAMETER [in]	2.06
DISCH. PASSAGE WIDTH [in]	0.064
DISCH. BLOCKAGE	0.9
SURFACE ROUGHNESS [in]	0.0001

BOUNDARY/OPERATING CONDITIONS
ELEMENTS #4,10,17: VANLESS DIFFUSER

IMPELLER DISCH. TIP DIAMETER [in]:			1.873		
IMPELLER DISCH. HUP DIAMETER [in].			1.873		
INLET PRESSURE [PSIA]:			0.000		
INLET BYPASS FLOW RATE [%].			0.000 (-5.975 For Element # 17)		
INLET CU [ft/s]:	502.71	499.30	495.94	492.61	488.54
	486.10	482.90	479.74	476.62	473.54
INLET TEMP. [R]:	37.80	37.80	37.80	37.80	37.80
	37.80	37.80	37.80	37.80	37.80

GEOMETRY
ELEMENTS #5,11: VANED DIFFUSER

INLET TIP DIAMETER [in]	2.06
INLET HUB DIAMETER [in]	2.06
INLET PASSAGE WIDTH [in]	0.064
INLET BLADE ANGLE [deg]	5
NUMBER OF INLET VANES	3
INLET NORMAL THICKNESS [in]	0.01
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	3
DISCH. HUB DIAMETER [in]	3
DISCH. PASSAGE WIDTH [in]	0.064
DISCH. BLADE ANGLE [deg]	18
NUMBER OF DISCH. VANES	3
DISCH. NORMAL THICKNESS [in]	0.01
DISCH. BLOCKAGE	0.89
VANE LENGTH [in]	0.6
SURFACE ROUGHNESS [in]	0.0001

BOUNDARY/OPERATING CONDITIONS
ELEMENTS #5,11: VANED DIFFUSER

IMPELLER DISCH. TIP DIAMETER [in]:				1.873	
IMPELLER DISCH. HUP DIAMETER [in]:				1.873	
INLET PRESSURE [PSIA]				0.000	
INLET BYPASS FLOW RATE [%]				0.000	
INLET CU [ft/s]	457.08	453.98	450.92	447.90	444.19
	441.97	439.07	436.20	433.36	430.55
INLET TEMP. [R] ·	37.80	37.80	37.80	37.80	37.80
	37.80	37.80	37.80	37.80	37.80

GEOMETRY
ELEMENTS #6,12: TURNING CHANNEL

INLET HYDRAULIC DIAMETER[in]	0.45
DISCH. HYDRAULIC DIAMETER[in]	0.53
PASSAGE LENGTH [in]	1.2
SURFACE ROUGHNESS[in]	0.0001
NUMBER OF CHANNELS	3
BLOCKAGE	0.9

GEOMETRY
ELEMENTS #7,13: DOWNCOMER

INLET HYDRAULIC DIAMETER[in]	0.53
DISCH. HYDRAULIC DIAMETER[in]	0.59
PASSAGE LENGTH [in]	1
SURFACE ROUGHNESS[in]	0.0001
NUMBER OF DOWNCOMERS	3
BLOCKAGE	0.85

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 9: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF.			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 9:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	0.01246	0.10241
11.78	0.114	0.018877	0.01248	0.08734
13.52	0.131	0.021653	0.01250	0.07614
15.25	0.147	0.024429	0.01251	0.06749
17.41	0.168	0.027886	0.01252	0.05912
18.71	0.181	0.029978	0.01252	0.05500
20.45	0.198	0.032750	0.01252	0.05034
22.18	0.214	0.035522	0.01251	0.04641
23.91	0.231	0.038293	0.01249	0.04306
25.63	0.248	0.041063	0.01248	0.04015

BOUNDARY/OPERATING CONDITIONS
ELEMENT #14: LEAKAGE w/ RS RWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
REAR WEAR RING LEAKAGE COEF.			0.015		
REAR WEAR RING CLEARANCE [in]			0.001		
REAR WEAR RING DIAMETER [in]			0.400		
% REAR WEAR RING STATIC HEAD LOST			0.150		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #14: LEAKAGE w/ RS RWR

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	-0.00272	0.10286
11.78	0.114	0.018877	0.00578	0.08772
13.52	0.131	0.021653	0.00739	0.07647
15.25	0.147	0.024429	0.00842	0.06778
17.41	0.168	0.027886	0.00931	0.05938
18.71	0.181	0.029978	0.00973	0.05524
20.45	0.198	0.032750	0.01018	0.05056
22.18	0.214	0.035522	0.01053	0.04662
23.91	0.231	0.038293	0.01082	0.04324
25.63	0.248	0.041063	0.01105	0.04033

BOUNDARY/OPERATING CONDITIONS
ELEMENT #16: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF.			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #16: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	0.01246	0.10241
11.78	0.114	0.018877	0.01248	0.08734
13.52	0.131	0.021653	0.01250	0.07614
15.25	0.147	0.024429	0.01251	0.06749
17.41	0.168	0.027886	0.01252	0.05912
18.71	0.181	0.029978	0.01252	0.05500
20.45	0.198	0.032750	0.01252	0.05034
22.18	0.214	0.035522	0.01251	0.04641
23.91	0.231	0.038293	0.01249	0.04306
25.63	0.248	0.041063	0.01248	0.04015

GEOMETRY
ELEMENT #18: 1-DISC. VOLUTE

THROAT DIAMETER [in]	0.17
THROAT AREA [in^2]	0.023
BLOCKAGE	0.95
SURFACE ROUGHNESS	0.0001

GEOMETRY
ELEMENT #19: 1-DISC. EXIT DIFF.

THROAT AREA [in^2]	0.023
INLET BLOCKAGE	0.95
EXIT DIAMETER [in]	0.35
EXIT BLOCKAGE	0.9

FLUID VELOCITIES
INDUCER INLET
(ELEMENT # 1 NODE # 1)
IMPELLER SPEED[RPM] 74000
URMS[ft/s] = 164.32

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
7.96	0.077	0.02344	14.19	0.00	14.19	113.21
9.55	0.093	0.02813	17.03	0.00	17.03	135.86
11.14	0.108	0.03282	19.87	0.00	19.87	158.50
12.73	0.124	0.03751	22.70	0.00	22.70	181.14
14.71	0.143	0.04335	26.24	0.00	26.24	209.36
15.91	0.155	0.04689	28.38	0.00	28.38	226.43
17.50	0.170	0.05158	31.22	0.00	31.22	249.07
19.09	0.186	0.05627	34.05	0.00	34.05	271.71
20.68	0.201	0.06095	36.89	0.00	36.89	294.36
22.27	0.217	0.06564	39.73	0.00	39.73	317.00

FLUID VELOCITIES
INDUCER DISCHARGE
(ELEMENT # 1 NODE # 2)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] 172.91

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
8.01	0.077	0.02707	16.39	93.14	94.57	76.92
9.61	0.093	0.03249	19.66	77.18	79.65	92.30
11.21	0.108	0.03790	22.94	61.23	65.39	107.69
12.81	0.124	0.04332	26.22	45.28	52.32	123.07
14.81	0.143	0.05006	30.30	25.40	39.54	142.24
16.02	0.155	0.05415	32.77	13.37	35.39	153.84
17.62	0.170	0.05956	36.05	-2.59	-36.14	169.22
19.22	0.186	0.06497	39.33	-18.54	-43.48	184.60
20.82	0.201	0.07039	42.60	-34.50	-54.82	199.99
22.42	0.217	0.07580	45.88	-50.45	-68.19	215.37

FLOW ANGLES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) BETA FLUID [deg]	INLET(NODE # 1) ALPHA (RMS) [deg]	INLET(NODE # 1) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 2) BETA FLUID [deg]	DISCHARGE(NODE # 2) ALPHA (RMS) [deg]	DISCHARGE(NODE # 2) DEVIATION ANGLE [deg]
8.01	0.077	4.94	90.00	2.26	11.61	9.98	0.69
9.61	0.093	5.92	90.00	1.28	11.61	14.29	0.69
11.21	0.108	6.89	90.00	0.31	11.61	20.54	0.69
12.81	0.124	7.87	90.00	-0.67	11.61	30.07	0.69
14.81	0.143	9.07	90.00	-1.87	11.61	50.03	0.69
16.02	0.155	9.80	90.00	-2.60	11.61	67.81	0.69
17.62	0.170	10.76	90.00	-3.56	11.61	-85.89	0.69
19.22	0.186	11.71	90.00	-4.51	11.61	-64.76	0.69
20.82	0.201	12.65	90.00	-5.45	11.61	-51.00	0.69
22.42	0.217	13.59	90.00	-6.39	11.61	-42.28	0.69

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 2 NODE # 2)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] 172.91

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
9.19	0.089	0.03016	18.25	93.14	94.91	52.62
10.81	0.104	0.03546	21.46	77.18	80.11	61.86
12.42	0.120	0.04076	24.67	61.23	66.01	71.12
14.04	0.136	0.04608	27.89	45.28	53.18	80.39
16.06	0.155	0.05271	31.90	25.40	40.78	91.96
17.29	0.167	0.05673	34.34	13.37	36.85	98.97
18.92	0.183	0.06207	37.57	-2.59	-37.66	108.28
20.54	0.199	0.06741	40.80	-18.54	-44.82	117.61
22.18	0.214	0.07277	44.04	-34.50	-55.94	126.95
23.81	0.230	0.07813	47.29	-50.45	-69.15	136.29

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 2 NODE # 3)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] 605.25

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
9.19	0.089	0.01472	8.91	502.71	502.79	13.86
10.81	0.104	0.01731	10.48	499.30	499.41	16.30
12.42	0.120	0.01990	12.04	495.94	496.08	18.74
14.04	0.136	0.02249	13.61	492.61	492.80	21.18
16.06	0.155	0.02573	15.57	488.54	488.79	24.23
17.29	0.167	0.02770	16.76	486.10	486.39	26.08
18.92	0.183	0.03030	18.34	482.90	483.25	28.53
20.54	0.199	0.03291	19.92	479.74	480.16	30.99
22.18	0.214	0.03552	21.50	476.62	477.11	33.45
23.81	0.230	0.03814	23.08	473.54	474.10	35.91

FLOW ANGLES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 2) BETA FLUID [deg]	INLET ALPHA (RMS) [deg]	INLET DEVIATION ANGLE [deg]	DISCHARGE(NODE # 3) BETA FLUID [deg]	DISCHARGE ALPHA (RMS) [deg]	DISCHARGE DEVIATION ANGLE [deg]
9.19	0.089	12.89	11.09	7.41	4.97	1.02	35.03
10.81	0.104	12.64	15.54	7.66	5.65	1.20	34.35
12.42	0.120	12.46	21.95	7.84	6.29	1.39	33.71
14.04	0.136	12.33	31.63	7.97	6.89	1.58	33.11
16.06	0.155	12.20	51.48	8.10	7.60	1.83	32.40
17.29	0.167	12.15	68.73	8.15	8.01	1.97	31.99
18.92	0.183	12.08	-86.06	8.22	8.53	2.17	31.47
20.54	0.199	12.03	-65.56	8.27	9.02	2.38	30.98
22.18	0.214	11.99	-51.93	8.31	9.49	2.58	30.51
23.81	0.230	11.95	-43.14	8.35	9.94	2.79	30.06

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 4 NODE # 3)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.01	0.077	0.01253	7.58	502.71	502.77
9.61	0.093	0.01503	9.10	499.30	499.39
11.21	0.108	0.01754	10.61	495.94	496.05
12.81	0.124	0.02004	12.13	492.61	492.77
14.81	0.143	0.02316	14.02	488.54	488.74
16.02	0.155	0.02505	15.16	486.10	486.34
17.62	0.170	0.02756	16.68	482.90	483.19
19.22	0.186	0.03006	18.19	479.74	480.09
20.82	0.201	0.03257	19.71	476.62	477.03
22.42	0.217	0.03507	21.23	473.54	474.01

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 4 NODE # 4)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.11	0.077	0.01153	6.98	457.08	457.13
9.73	0.093	0.01384	8.38	453.98	454.05
11.35	0.108	0.01614	9.77	450.92	451.02
12.97	0.124	0.01845	11.17	447.90	448.04
14.99	0.143	0.02132	12.91	444.19	444.38
16.22	0.155	0.02306	13.96	441.97	442.20
17.84	0.170	0.02537	15.35	439.07	439.34
19.46	0.186	0.02768	16.75	436.20	436.52
21.08	0.201	0.02998	18.15	433.36	433.74
22.70	0.217	0.03229	19.54	430.55	430.99

FLOW ANGLES
ELEMENT # 4:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 74000

		INLET(NODE # 3)			DISCHARGE(NODE # 4)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
8.11	0.077	0.86	0.86	-0.86	0.87	0.87	-0.87
9.73	0.093	1.04	1.04	-1.04	1.06	1.06	-1.06
11.35	0.108	1.23	1.23	-1.23	1.24	1.24	-1.24
12.97	0.124	1.41	1.41	-1.41	1.43	1.43	-1.43
14.99	0.143	1.64	1.64	-1.64	1.66	1.66	-1.66
16.22	0.155	1.79	1.79	-1.79	1.81	1.81	-1.81
17.84	0.170	1.98	1.98	-1.98	2.00	2.00	-2.00
19.46	0.186	2.17	2.17	-2.17	2.20	2.20	-2.20
21.08	0.201	2.37	2.37	-2.37	2.40	2.40	-2.40
22.70	0.217	2.57	2.57	-2.57	2.60	2.60	-2.60

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT # 5 NODE # 4)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.11	0.077	0.01226	7.42	457.08	457.14
9.73	0.093	0.01471	8.90	453.98	454.06
11.35	0.108	0.01716	10.39	450.92	451.04
12.97	0.124	0.01961	11.87	447.90	448.06
14.99	0.143	0.02266	13.72	444.19	444.40
16.22	0.155	0.02451	14.84	441.97	442.22
17.84	0.170	0.02696	16.32	439.07	439.37
19.46	0.186	0.02941	17.80	436.20	436.56
21.08	0.201	0.03187	19.29	433.36	433.79
22.70	0.217	0.03432	20.77	430.55	431.05

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT # 5 NODE # 5)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
7.98	0.077	0.00797	4.82	26.64	27.07
9.57	0.093	0.00956	5.79	31.96	32.48
11.17	0.108	0.01116	6.75	37.29	37.90
12.76	0.124	0.01275	7.72	42.62	43.31
14.75	0.143	0.01474	8.92	49.25	50.06
15.95	0.155	0.01594	9.65	53.27	54.14
17.55	0.170	0.01753	10.61	58.60	59.55
19.15	0.186	0.01913	11.58	63.93	64.97
20.74	0.201	0.02072	12.54	69.25	70.38
22.34	0.217	0.02232	13.51	74.58	75.79

FLOW ANGLES
ELEMENT # 5:VANED DIFFUSER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 4) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 5) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
7.98	0.077	0.93	0.93	4.07	10.27	10.27	7.73
9.57	0.093	1.12	1.12	3.88	10.27	10.27	7.73
11.17	0.108	1.32	1.32	3.68	10.27	10.27	7.73
12.76	0.124	1.52	1.52	3.48	10.27	10.27	7.73
14.75	0.143	1.77	1.77	3.23	10.27	10.27	7.73
15.95	0.155	1.92	1.92	3.08	10.27	10.27	7.73
17.55	0.170	2.13	2.13	2.87	10.27	10.27	7.73
19.15	0.186	2.34	2.34	2.66	10.27	10.27	7.73
20.74	0.201	2.55	2.55	2.45	10.27	10.27	7.73
22.34	0.217	2.76	2.76	2.24	10.27	10.27	7.73

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT # 6 NODE # 5)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
7.98	0.077	5.96	26.64	27.29
9.57	0.093	7.15	31.96	32.75
11.17	0.108	8.35	37.29	38.21
12.76	0.124	9.54	42.62	43.67
14.75	0.143	11.02	49.25	50.47
15.95	0.155	11.92	53.27	54.59
17.55	0.170	13.11	58.60	60.05
19.15	0.186	14.31	63.93	65.51
20.74	0.201	15.50	69.25	70.97
22.34	0.217	16.69	74.58	76.42

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT # 6 NODE # 6)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
7.98	0.077	0.00	0.00	19.68
9.57	0.093	0.00	0.00	23.61
11.17	0.108	0.00	0.00	27.55
12.76	0.124	0.00	0.00	31.48
14.75	0.143	0.00	0.00	36.38
15.95	0.155	0.00	0.00	39.35
17.55	0.170	0.00	0.00	43.29
19.14	0.186	0.00	0.00	47.22
20.74	0.201	0.00	0.00	51.16
22.34	0.217	0.00	0.00	55.09

FLOW ANGLES
ELEMENT # 6:TURNING CHANNEL

IMPELLER SPEED[RPM] 74000

		INLET(NODE # 5)			DISCHARGE(NODE # 6)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
7.98	0.077	0.93	0.93	4.07	10.27	10.27	7.73
9.57	0.093	1.12	1.12	3.88	10.27	10.27	7.73
11.17	0.108	1.32	1.32	3.68	10.27	10.27	7 73
12.76	0.124	1.52	1.52	3.48	10.27	10.27	7.73
14.75	0.143	1.77	1.77	3.23	10.27	10.27	7.73
15.95	0.155	1.92	1.92	3.08	10.27	10.27	7.73
17.55	0.170	2.13	2.13	2.87	10.27	10.27	7.73
19.14	0.186	2.34	2.34	2.66	10.27	10.27	7.73
20.74	0.201	2.55	2.55	2.45	10.27	10.27	7.73
22.34	0.217	2.76	2.76	2.24	10.27	10.27	7.73

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT # 7 NODE # 6)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
7.98	0.077	0.00	0.00	4.55
9.57	0.093	0.00	0.00	5.46
11.17	0.108	0.00	0.00	6.37
12.76	0.124	0.00	0.00	7.28
14.75	0.143	0.00	0.00	8.41
15.95	0.155	0.00	0.00	9.10
17.55	0.170	0.00	0.00	10.01
19.14	0.186	0.00	0.00	10.92
20.74	0.201	0.00	0.00	11.83
22.34	0.217	0.00	0.00	12.74

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT # 7 NODE # 7)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.01	0.077	0.00	0.00	3.69
9.61	0.093	0.00	0.00	4.42
11.21	0.108	0.00	0.00	5.16
12.81	0.124	0.00	0.00	5.90
14.81	0.143	0.00	0.00	6.82
16.02	0.155	0.00	0.00	7.37
17.62	0.170	0.00	0.00	8.11
19.22	0.186	0.00	0.00	8.85
20.82	0.201	0.00	0.00	9.58
22.42	0.217	0.00	0.00	10.32

FLOW ANGLES
ELEMENT # 7:DOWNCOMER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 6) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 7) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
8.01	0.077	0.93	90.00	4.07	10.27	90.00	7.73
9.61	0.093	1.12	90.00	3.88	10.27	90.00	7.73
11.21	0.108	1.32	90.00	3.68	10.27	90.00	7.73
12.81	0.124	1.52	90.00	3.48	10.27	90.00	7.73
14.81	0.143	1.77	90.00	3.23	10.27	90.00	7.73
16.02	0.155	1.92	90.00	3.08	10.27	90.00	7.73
17.62	0.170	2.13	90.00	2.87	10.27	90.00	7.73
19.22	0.186	2.34	90.00	2.66	10.27	90.00	7.73
20.82	0.201	2.55	90.00	2.45	10.27	90.00	7.73
22.42	0.217	2.76	90.00	2.24	10.27	90.00	7.73

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 8 NODE # 7)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] = 172.91

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
10.05	0.097	0.03298	19.96	0.00	19.96	57.53
11.78	0.114	0.03867	23.40	0.00	23.40	67.46
13.52	0.131	0.04436	26.85	0.00	26.85	77.38
15.25	0.147	0.05004	30.29	0.00	30.29	87.30
17.41	0.168	0.05712	34.57	0.00	34.57	99.65
18.71	0.181	0.06141	37.17	0.00	37.17	107.13
20.45	0.198	0.06709	40.60	0.00	40.60	117.04
22.18	0.214	0.07277	44.04	0.00	44.04	126.94
23.91	0.231	0.07844	47.48	0.00	47.48	136.85
25.63	0.248	0.08412	50.91	0.00	50.91	146.74

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 8 NODE # 8)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] = 605.25

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
10.05	0.097	0.01610	9.74	500.89	500.99	15.16
11.78	0.114	0.01888	11.43	497.26	497.39	17.77
13.52	0.131	0.02165	13.11	493.69	493.86	20.39
15.25	0.147	0.02443	14.79	490.17	490.39	23.00
17.41	0.168	0.02789	16.88	485.86	486.16	26.26
18.71	0.181	0.02998	18.14	483.30	483.64	28.23
20.45	0.198	0.03275	19.82	479.94	480.35	30.84
22.18	0.214	0.03552	21.50	476.62	477.11	33.45
23.91	0.231	0.03829	23.18	473.36	473.92	36.06
25.63	0.248	0.04106	24.85	470.13	470.79	38.67

FLOW ANGLES
ELEMENT # 8:IMPELLER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 7) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 8) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
10.05	0.097	6.58	90.00	13.72	5.33	1.11	34.67
11.78	0.114	7.71	90.00	12.59	6.04	1.32	33.96
13.52	0.131	8.83	90.00	11.47	6.70	1.52	33.30
15.25	0.147	9.94	90.00	10.36	7.32	1.73	32.68
17.41	0.168	11.31	90.00	8.99	8.05	1.99	31.95
18.71	0.181	12.13	90.00	8.17	8.46	2.15	31.54
20.45	0.198	13.22	90.00	7.08	8.99	2.37	31.01
22.18	0.214	14.29	90.00	6.01	9.49	2.58	30.51
23.91	0.231	15.35	90.00	4.95	9.97	2.80	30.03
25.63	0.248	16.41	90.00	3.89	10.42	3.03	29.58

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT #10 NODE # 8)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.48	0.082	0.01327	8.03	500.89	500.96
11.09	0.107	0.01735	10.50	497.26	497.37
12.99	0.126	0.02032	12.30	493.69	493.84
14.83	0.143	0.02319	14.04	490.17	490.37
17.08	0.165	0.02671	16.17	485.86	486.14
18.43	0.178	0.02882	17.44	483.30	483.61
20.20	0.195	0.03160	19.13	479.94	480.32
21.97	0.212	0.03437	20.80	476.62	477.08
23.73	0.229	0.03712	22.47	473.36	473.89
25.49	0.246	0.03987	24.13	470.13	470.75

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT #10 NODE # 9)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.60	0.082	0.01223	7.40	455.42	455.48
11.25	0.107	0.01600	9.68	452.12	452.22
13.17	0.126	0.01873	11.34	448.87	449.02
15.04	0.143	0.02139	12.94	445.67	445.86
17.32	0.165	0.02463	14.91	441.76	442.01
18.69	0.178	0.02658	16.08	439.43	439.72
20.49	0.195	0.02914	17.64	436.37	436.73
22.28	0.212	0.03169	19.18	433.36	433.78
24.07	0.229	0.03423	20.72	430.39	430.89
25.85	0.246	0.03676	22.25	427.45	428.03

FLOW ANGLES
ELEMENT #10: VANLESS DIFFUSER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 8) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 9) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
8.60	0.082	0.92	0.92	-0.92	0.93	0.93	-0.93
11.25	0.107	1.21	1.21	-1.21	1.23	1.23	-1.23
13.17	0.126	1.43	1.43	-1.43	1.45	1.45	-1.45
15.04	0.143	1.64	1.64	-1.64	1.66	1.66	-1.66
17.32	0.165	1.91	1.91	-1.91	1.93	1.93	-1.93
18.69	0.178	2.07	2.07	-2.07	2.10	2.10	-2.10
20.49	0.195	2.28	2.28	-2.28	2.31	2.31	-2.31
22.28	0.212	2.50	2.50	-2.50	2.53	2.53	-2.53
24.07	0.229	2.72	2.72	-2.72	2.76	2.76	-2.76
25.85	0.246	2.94	2.94	-2.94	2.98	2.98	-2.98

FLUID VELOCITIES
VANED DIFFUSER INLET
(ELEMENT #11 NODE # 9)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.60	0.082	0.01300	7.87	455.42	455.49
11.25	0.107	0.01700	10.29	452.12	452.24
13.17	0.126	0.01991	12.05	448.87	449.03
15.04	0.143	0.02273	13.76	445.67	445.89
17.32	0.165	0.02618	15.84	441.76	442.05
18.69	0.178	0.02825	17.10	439.43	439.76
20.49	0.195	0.03097	18.74	436.37	436.77
22.28	0.212	0.03368	20.39	433.36	433.84
24.07	0.229	0.03638	22.02	430.39	430.95
25.85	0.246	0.03907	23.65	427.45	428.11

FLUID VELOCITIES
VANED DIFFUSER DISCHARGE
(ELEMENT #11 NODE #10)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.47	0.082	0.00846	5.12	28.27	28.73
11.07	0.107	0.01106	6.70	36.97	37.57
12.97	0.126	0.01296	7.84	43.30	44.00
14.80	0.143	0.01479	8.95	49.42	50.23
17.05	0.165	0.01703	10.31	56.93	57.85
18.40	0.178	0.01838	11.12	61.42	62.42
20.17	0.195	0.02015	12.20	67.35	68.44
21.94	0.212	0.02192	13.26	73.24	74.43
23.69	0.229	0.02367	14.33	79.11	80.40
25.45	0.246	0.02542	15.39	84.96	86.34

FLOW ANGLES
ELEMENT #11: VANED DIFFUSER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 9) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE #10) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
8.47	0.082	0.99	0.99	4.01	10.27	10.27	7.73
11.07	0.107	1.30	1.30	3.70	10.27	10.27	7.73
12.97	0.126	1.54	1.54	3.46	10.27	10.27	7.73
14.80	0.143	1.77	1.77	3.23	10.27	10.27	7.73
17.05	0.165	2.05	2.05	2.95	10.27	10.27	7.73
18.40	0.178	2.23	2.23	2.77	10.27	10.27	7.73
20.17	0.195	2.46	2.46	2.54	10.27	10.27	7.73
21.94	0.212	2.69	2.69	2.31	10.27	10.27	7.73
23.69	0.229	2.93	2.93	2.07	10.27	10.27	7.73
25.45	0.246	3.17	3.17	1.83	10.27	10.27	7.73

FLUID VELOCITIES
TURNING CHANNEL INLET
(ELEMENT #12 NODE #10)
IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.47	0.082	6.33	28.27	28.97
11.07	0.107	8.27	36.97	37.89
12.97	0.126	9.69	43.30	44.37
14.80	0.143	11.06	49.42	50.65
17.05	0.165	12.74	56.93	58.33
18.40	0.178	13.75	61.42	62.94
20.17	0.195	15.07	67.35	69.01
21.94	0.212	16.39	73.24	75.05
23.69	0.229	17.70	79.11	81.07
25.45	0.246	19.01	84.96	87.06

FLUID VELOCITIES
TURNING CHANNEL DISCHARGE
(ELEMENT #12 NODE #11)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.47	0.082	0.00	0.00	20.88
11.07	0.107	0.00	0.00	27.31
12.97	0.126	0.00	0.00	31.99
14.80	0.143	0.00	0.00	36.51
17.05	0.165	0.00	0.00	42.05
18.39	0.178	0.00	0.00	45.37
20.17	0.195	0.00	0.00	49.75
21.93	0.212	0.00	0.00	54.10
23.69	0.229	0.00	0.00	58.44
25.44	0.246	0.00	0.00	62.76

FLOW ANGLES
ELEMENT #12: TURNING CHANNEL

IMPELLER SPEED[RPM] = 74000

		INLET(NODE #10)			DISCHARGE(NODE #11)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
8.47	0.082	0.99	0.99	4.01	10.27	10.27	7.73
11.07	0.107	1.30	1.30	3.70	10.27	10.27	7.73
12.97	0.126	1.54	1.54	3.46	10.27	10.27	7.73
14.80	0.143	1.77	1.77	3.23	10.27	10.27	7 73
17.05	0.165	2.05	2.05	2.95	10.27	10.27	7.73
18.39	0.178	2.23	2.23	2.77	10.27	10.27	7.73
20.17	0.195	2.46	2.46	2.54	10.27	10.27	7.73
21.93	0.212	2.69	2.69	2.31	10.27	10.27	7.73
23.69	0.229	2.93	2.93	2.07	10.27	10.27	7.73
25.44	0.246	3.17	3.17	1.83	10.27	10.27	7.73

FLUID VELOCITIES
DOWNCOMER INLET
(ELEMENT #13 NODE #11)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.47	0.082	0.00	0.00	4.83
11.07	0.107	0.00	0.00	6.32
12.97	0.126	0.00	0.00	7.40
14.80	0.143	0.00	0.00	8.44
17.05	0.165	0.00	0.00	9.72
18.39	0.178	0.00	0.00	10.49
20.17	0.195	0.00	0.00	11.50
21.93	0.212	0.00	0.00	12.51
23.69	0.229	0.00	0.00	13.51
25.44	0.246	0.00	0.00	14.51

FLUID VELOCITIES
DOWNCOMER DISCHARGE
(ELEMENT #13 NODE #12)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
8.48	0.082	0.00	0.00	3.90
11.09	0.107	0.00	0.00	5.10
12.99	0.126	0.00	0.00	5.98
14.83	0.143	0.00	0.00	6.82
17.08	0.165	0.00	0.00	7.86
18.43	0.178	0.00	0.00	8.48
20.20	0.195	0.00	0.00	9.30
21.97	0.212	0.00	0.00	10.11
23.73	0.229	0.00	0.00	10.92
25.49	0.246	0.00	0.00	11.73

FLOW ANGLES
ELEMENT #13: DOWNCOMER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #11) BETA FLUID [deg]	INLET(NODE #11) ALPHA (RMS) [deg]	INLET(NODE #11) DEVIATION ANGLE [deg]	DISCHARGE(NODE #12) BETA FLUID [deg]	DISCHARGE(NODE #12) ALPHA (RMS) [deg]	DISCHARGE(NODE #12) DEVIATION ANGLE [deg]
8.48	0.082	0.99	90.00	4.01	10.27	90.00	7.73
11.09	0.107	1.30	90.00	3.70	10.27	90.00	7.73
12.99	0.126	1.54	90.00	3.46	10.27	90.00	7 73
14.83	0.143	1.77	90.00	3.23	10.27	90.00	7 73
17.08	0.165	2.05	90.00	2.95	10.27	90.00	7.73
18.43	0.178	2.23	90.00	2.77	10.27	90.00	7.73
20.20	0.195	2.46	90.00	2.54	10.27	90.00	7.73
21.97	0.212	2.69	90.00	2.31	10.27	90.00	7.73
23.73	0.229	2.93	90.00	2.07	10.27	90.00	7.73
25.49	0.246	3.17	90.00	1.83	10.27	90.00	7.73

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT #15 NODE #12)
IMPELLER SPEED[RPM] = 74000
URMS[ft/s] 172.91

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
10.05	0.097	0.03298	19.96	0.00	19.96	57.53
11.78	0.114	0.03867	23.40	0.00	23.40	67.46
13.52	0.131	0.04436	26.85	0.00	26.85	77.38
15.25	0.147	0.05004	30.29	0.00	30.29	87.30
17.41	0.168	0.05712	34.57	0.00	34.57	99.65
18.71	0.181	0.06141	37.17	0.00	37.17	107.13
20.45	0.198	0.06709	40.60	0.00	40.60	117.04
22.18	0.214	0.07277	44.04	0.00	44.04	126.94
23.91	0.231	0.07844	47.48	0.00	47.48	136.85
25.63	0.248	0.08412	50.91	0.00	50.91	146.74

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT #15 NODE #13)
IMPELLER SPEED[RPM] 74000
URMS[ft/s] = 605.25

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
10.05	0.097	0.01610	9.74	500.89	500.99	15.16
11.78	0.114	0.01888	11.43	497.26	497.39	17.77
13.52	0.131	0.02165	13.11	493.69	493.86	20.39
15.25	0.147	0.02443	14.79	490.17	490.39	23.00
17.41	0.168	0.02789	16.88	485.86	486.16	26.26
18.71	0.181	0.02998	18.14	483.30	483.64	28.23
20.45	0.198	0.03275	19.82	479.94	480.35	30.84
22.18	0.214	0.03552	21.50	476.62	477.11	33.45
23.91	0.231	0.03829	23.18	473.36	473.92	36.06
25.63	0.248	0.04106	24.85	470.13	470.79	38.67

FLOW ANGLES
ELEMENT #15: IMPELLER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #12) BETA FLUID [deg]	INLET(NODE #12) ALPHA (RMS) [deg]	INLET(NODE #12) DEVIATION ANGLE [deg]	DISCHARGE(NODE #13) BETA FLUID [deg]	DISCHARGE(NODE #13) ALPHA (RMS) [deg]	DISCHARGE(NODE #13) DEVIATION ANGLE [deg]
10.05	0.097	6.58	90.00	13.72	5.33	1.11	34.67
11.78	0.114	7.71	90.00	12.59	6.04	1.32	33.96
13.52	0.131	8.83	90.00	11.47	6.70	1.52	33.30
15.25	0.147	9.94	90.00	10.36	7.32	1.73	32.68
17.41	0.168	11.31	90.00	8.99	8.05	1.99	31.95
18.71	0.181	12.13	90.00	8.17	8.46	2.15	31.54
20.45	0.198	13.22	90.00	7.08	8.99	2.37	31.01
22.18	0.214	14.29	90.00	6.01	9.49	2.58	30.51
23.91	0.231	15.35	90.00	4.95	9.97	2.80	30.03
25.63	0.248	16.41	90.00	3.89	10.42	3.03	29.58

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT #17 NODE #13)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.28	0.090	0.01452	8.79	500.89	500.97
11.12	0.107	0.01739	10.53	497.26	497.37
12.96	0.125	0.02026	12.27	493.69	493.84
14.79	0.143	0.02313	14.00	490.17	490.37
17.08	0.165	0.02671	16.17	485.86	486.14
18.46	0.178	0.02888	17.48	483.30	483.62
20.29	0.196	0.03175	19.21	479.94	480.32
22.13	0.214	0.03462	20.95	476.62	477.09
23.96	0.232	0.03748	22.69	473.36	473.90
25.80	0.249	0.04035	24.42	470.13	470.77

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT #17 NODE #14)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.43	0.090	0.01341	8.12	455.42	455.50
11.29	0.107	0.01606	9.72	452.12	452.23
13.15	0.125	0.01871	11.32	448.87	449.02
15.02	0.143	0.02136	12.93	445.67	445.86
17.34	0.165	0.02466	14.93	441.76	442.01
18.74	0.178	0.02666	16.13	439.43	439.72
20.61	0.196	0.02931	17.74	436.37	436.73
22.47	0.214	0.03196	19.34	433.36	433.79
24.33	0.232	0.03461	20.95	430.39	430.90
26.19	0.249	0.03726	22.55	427.45	428.05

FLOW ANGLES
ELEMENT #17: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE #13) BETA FLUID [deg]	INLET(NODE #13) ALPHA (RMS) [deg]	INLET(NODE #13) DEVIATION ANGLE [deg]	DISCHARGE(NODE #14) BETA FLUID [deg]	DISCHARGE(NODE #14) ALPHA (RMS) [deg]	DISCHARGE(NODE #14) DEVIATION ANGLE [deg]
9.43	0.090	1.01	1.01	-1.01	1.02	1.02	-1.02
11.29	0.107	1.21	1.21	-1.21	1.23	1.23	-1.23
13.15	0.125	1.42	1.42	-1.42	1.45	1.45	-1.45
15.02	0.143	1.64	1.64	-1.64	1.66	1.66	-1.66
17.34	0.165	1.91	1.91	-1.91	1.94	1.94	-1.94
18.74	0.178	2.07	2.07	-2.07	2.10	2.10	-2.10
20.61	0.196	2.29	2.29	-2.29	2.33	2.33	-2.33
22.47	0.214	2.52	2.52	-2.52	2.56	2.56	-2.56
24.33	0.232	2.74	2.74	-2.74	2.79	2.79	-2.79
26.19	0.249	2.97	2.97	-2.97	3.02	3.02	-3.02

FLUID VELOCITIES
1-DISC. VOLUTE INLET
(ELEMENT #18 NODE #14)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.43	0.090	8.12	455.42	455.50
11.29	0.107	9.72	452.12	452.23
13.15	0.125	11.32	448.87	449.02
15.02	0.143	12.93	445.67	445.86
17.34	0.165	14.93	441.76	442.01
18.74	0.178	16.13	439.43	439.72
20.61	0.196	17.74	436.37	436.73
22.47	0.214	19.34	433.36	433.79
24.33	0.232	20.95	430.39	430.90
26.19	0.249	22.55	427.45	428.05

FLUID VELOCITIES
1-DISC. VOLUTE DISCHARGE
(ELEMENT #18 NODE #15)
IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.30	0.090	137.48	0.00	137.48
11.13	0.107	164.65	0.00	164.65
12.97	0.125	191.82	0.00	191.82
14.81	0.143	218.99	0.00	218.99
17.10	0.165	252.84	0.00	252.84
18.48	0.178	273.32	0.00	273.32
20.32	0.196	300.49	0.00	300.49
22.16	0.214	327.66	0.00	327.66
23.99	0.232	354.82	0.00	354.82
25.83	0.249	381.99	0.00	381.99

FLOW ANGLES
ELEMENT #18: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] = 74000

		INLET(NODE #14)			DISCHARGE(NODE #15)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
9.30	0.090	1.02	1.02	-1.01	90.00	90.00	-1.02
11.13	0.107	1.23	1.23	-1.21	90.00	90.00	-1.23
12.97	0.125	1.45	1.45	-1.42	90.00	90.00	-1.45
14.81	0.143	1.66	1.66	-1.64	90.00	90.00	-1.66
17.10	0.165	1.94	1.94	-1.91	90.00	90.00	-1.94
18.48	0.178	2.10	2.10	-2.07	90.00	90.00	-2.10
20.32	0.196	2.33	2.33	-2.29	90.00	90.00	-2.33
22.16	0.214	2.56	2.56	-2.52	90.00	90.00	-2.56
23.99	0.232	2.79	2.79	-2.74	90.00	90.00	-2.79
25.83	0.249	3.02	3.02	-2.97	90.00	90.00	-3.02

FLUID VELOCITIES
1-DISC. EXIT DIFF. INLET
(ELEMENT #19 NODE #15)
IMPELLER SPEED [RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.30	0.090	136.44	0.00	136.44
11.13	0.107	163.40	0.00	163.40
12.97	0.125	190.37	0.00	190.37
14.81	0.143	217.33	0.00	217.33
17.10	0.165	250.92	0.00	250.92
18.48	0.178	271.25	0.00	271.25
20.32	0.196	298.21	0.00	298.21
22.16	0.214	325.18	0.00	325.18
23.99	0.232	352.13	0.00	352.13
25.83	0.249	379.09	0.00	379.09

FLUID VELOCITIES
1-DISC. EXIT DIFF. DISCHARGE
(ELEMENT #19 NODE #16)
IMPELLER SPEED [RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
9.28	0.090	34.43	0.00	34.43
11.12	0.107	41.23	0.00	41.23
12.96	0.125	48.04	0.00	48.04
14.79	0.143	54.84	0.00	54.84
17.08	0.165	63.32	0.00	63.32
18.46	0.178	68.45	0.00	68.45
20.29	0.196	75.25	0.00	75.25
22.13	0.214	82.05	0.00	82.05
23.96	0.232	88.86	0.00	88.86
25.80	0.249	95.66	0.00	95.66

FLOW ANGLES
ELEMENT #19: 1-DISC. EXIT DIFF

IMPELLER SPEED [RPM] 74000

		INLET (NODE #15)			DISCHARGE (NODE #16)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
9.28	0.090	90.00	90.00	-1.01	90.00	90.00	-1.02
11.12	0.107	90.00	90.00	-1.21	90.00	90.00	-1.23
12.96	0.125	90.00	90.00	-1.42	90.00	90.00	-1.45
14.79	0.143	90.00	90.00	-1.64	90.00	90.00	-1.66
17.08	0.165	90.00	90.00	-1.91	90.00	90.00	-1.94
18.46	0.178	90.00	90.00	-2.07	90.00	90.00	-2.10
20.29	0.196	90.00	90.00	-2.29	90.00	90.00	-2.33
22.13	0.214	90.00	90.00	-2.52	90.00	90.00	-2.56
23.96	0.232	90.00	90.00	-2.74	90.00	90.00	-2.79
25.80	0.249	90.00	90.00	-2.97	90.00	90.00	-3.02

NODAL PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) TOTAL HEAD [ft]	TEMP [R]	NPSH AVAIL. [ft]	VAPOR PRES [PSIA]	STATIC PRES [PSIA]	DISCHARGE(NODE # 2) TOTAL HEAD [ft]	TEMP. [R]	STATIC PRES [PSIA]
8.01	0.077	610.1	37.8	597.5	18.127	18.4	1025.4	37.8	26.7
9.61	0.093	610.1	37.8	606.0	18.127	18.4	922.3	37.8	24.8
11.21	0.108	610.1	37.8	609.9	18.127	18.3	809.1	37.8	22.4
12.81	0.124	610.1	37.8	609.0	18.127	18.3	685.7	37.8	19.4
14.81	0.143	610.1	37.8	601.3	18.127	18.2	517.5	37.8	14.9
16.02	0.155	610.1	37.8	593.1	18.127	18.1	408.0	37.8	11.7
17.62	0.170	610.1	37.8	578.2	18.127	18.0	253.8	37.8	7.0
19.22	0.186	610.1	37.8	558.5	18.127	18.0	89.9	37.8	1.8
20.82	0.201	610.1	37.8	534.1	18.127	17.9	46.7	37.8	0.0
22.42	0.217	610.1	37.8	505.0	18.127	17.8	72.3	37.8	0.0

ELEMENT LOSSES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.01	0.077	311130.	0.00111	0.00577	0.00062	0.00749
9.61	0.093	373356.	0.00036	0.00825	0.00040	0.00901
11.21	0.108	435583.	0.00002	0.01116	0.00023	0.01142
12.81	0.124	497806.	0.00010	0.01452	0.00011	0.01473
14.81	0.143	575339.	0.00077	0.01933	0.00002	0.02012
16.02	0.155	622259.	0.00149	0.02257	0.00000	0.02406
17.62	0.170	684482.	0.00281	0.02727	0.00000	0.03007
19.22	0.186	746709.	0.00454	0.03241	0.00000	0.03694
20.82	0.201	808932.	0.00668	0.03798	0.00000	0.04466
22.42	0.217	871158.	0.00924	0.04400	0.00000	0.05323

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
8.01	0.08	311130.	0.0365	0.0440	0.8296	415.3	8.4	0.0
9.61	0.09	373356.	0.0274	0.0364	0.7527	312.2	6.6	0.0
11.21	0.11	435583.	0.0175	0.0289	0.6049	199.0	4.2	0.0
12.81	0.12	497806.	0.0066	0.0214	0.3106	75.6	1.2	0.0
14.81	0.14	575339.	-0.0081	0.0120	-0.6783	-92.6	-3.2	0.0
16.02	0.15	622259.	-0.0178	0.0063	-2.8137	-202.1	-6.3	0.0
17.62	0.17	684482.	-0.0313	-0.0012	25.6219	-356.3	-10.9	0.0
19.22	0.19	746709.	-0.0457	-0.0088	5.2207	-520.3	-16.0	0.0
20.82	0.20	808932.	-0.0495	-0.0163	3.7428	-563.4	-17.7	0.0
22.42	0.22	871158.	-0.0472	-0.0238	3.2354	-537.8	-17.6	0.0

ELEMENT LOSSES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
9.19	0.089	137691.	0.00063	0.00012	0.00010	0.00086
10.81	0.104	161876.	0.00097	0.00017	0.00001	0.00115
12.42	0.120	186097.	0.00138	0.00022	0.00000	0.00160
14.04	0.136	210356.	0.00186	0.00028	0.00000	0.00215
16.06	0.155	240638.	0.00256	0.00037	0.00002	0.00295
17.29	0.167	258991.	0.00304	0.00042	0.00003	0.00349
18.92	0.183	283359.	0.00373	0.00051	0.00006	0.00430
20.54	0.199	307762.	0.00449	0.00060	0.00009	0.00518
22.18	0.214	332195.	0.00533	0.00069	0.00013	0.00615
23.81	0.230	356659.	0.00623	0.00079	0.00016	0.00719

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 3: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF.			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 3:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
9.19	0.089	0.014724	0.01145	0.11198
10.81	0.104	0.017310	0.01157	0.09525
12.42	0.120	0.019900	0.01172	0.08285
14.04	0.136	0.022494	0.01189	0.07330
16.06	0.155	0.025732	0.01215	0.06407
17.29	0.167	0.027695	0.01232	0.05953
18.92	0.183	0.030301	0.01256	0.05441
20.54	0.199	0.032910	0.01283	0.05010
22.18	0.214	0.035523	0.01311	0.04641
23.81	0.230	0.038139	0.01342	0.04323

ELEMENT LOSSES
ELEMENT # 4:VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.11	0.077	2833917.	0.00000	0.17129	0.00000	0.17129
9.73	0.093	2814826.	0.00000	0.13988	0.00000	0.13988
11.35	0.108	2796032.	0.00000	0.11751	0.00000	0.11751
12.97	0.124	2777520.	0.00000	0.10079	0.00000	0.10079
14.99	0.143	2754831.	0.00000	0.08509	0.00000	0.08509
16.22	0.155	2741297.	0.00000	0.07752	0.00000	0.07752
17.84	0.170	2723572.	0.00000	0.06911	0.00000	0.06911
19.46	0.186	2706091.	0.00000	0.06214	0.00000	0.06214
21.08	0.201	2688850.	0.00000	0.05627	0.00000	0.05627
22.70	0.217	2671840.	0.00000	0.05127	0.00000	0.05127

ELEMENT LOSSES
ELEMENT # 5:VANED DIFFUSER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
7.98	0.077	217128.	0.09459	0.00068	0.10099	0.19626
9.57	0.093	260554.	0.08467	0.00098	0.09709	0.18273
11.17	0.108	303980.	0.07532	0.00132	0.09323	0.16987
12.76	0.124	347404.	0.06653	0.00172	0.08944	0.15769
14.75	0.143	401512.	0.05637	0.00228	0.08479	0.14343
15.95	0.155	434256.	0.05064	0.00265	0.08202	0.13531
17.55	0.170	477679.	0.04352	0.00320	0.07840	0.12512
19.15	0.186	521106.	0.03696	0.00380	0.07485	0.11560
20.74	0.201	564529.	0.03094	0.00444	0.07137	0.10675
22.34	0.217	607955.	0.02546	0.00514	0.06796	0.09856

ELEMENT LOSSES
ELEMENT # 6:TURNING CHANNEL

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
7.98	0.077	508266.	0.00000	0.00026	0.00000	0.00026
9.57	0.093	609920.	0.00000	0.00038	0.00000	0.00038
11.17	0.108	711575.	0.00000	0.00051	0.00000	0.00051
12.76	0.124	813223.	0.00000	0.00067	0.00000	0.00067
14.75	0.143	939882.	0.00000	0.00089	0.00000	0.00089
15.95	0.155	1016532.	0.00000	0.00104	0.00000	0.00104
17.55	0.170	1118180.	0.00000	0.00126	0.00000	0.00126
19.14	0.186	1219834.	0.00000	0.00150	0.00000	0.00150
20.74	0.201	1321482.	0.00000	0.00175	0.00000	0.00175
22.34	0.217	1423136.	0.00000	0.00203	0.00000	0.00203

ELEMENT LOSSES
ELEMENT # 7:DOWNCOMER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.01	0.077	139189.	0.00000	0.00000	0.00000	0.00000
9.61	0.093	167027.	0.00000	0.00000	0.00000	0.00000
11.21	0.108	194865.	0.00000	0.00000	0.00000	0.00000
12.81	0.124	222701.	0.00000	0.00000	0.00000	0.00000
14.81	0.143	257387.	0.00000	0.00000	0.00000	0.00000
16.02	0.155	278377.	0.00000	0.00001	0.00000	0.00001
17.62	0.170	306214.	0.00000	0.00001	0.00000	0.00001
19.22	0.186	334052.	0.00000	0.00001	0.00000	0.00001
20.82	0.201	361888.	0.00000	0.00001	0.00000	0.00001
22.42	0.217	389726.	0.00000	0.00001	0.00000	0.00001

ELEMENT LOSSES
ELEMENT # 8:IMPELLER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
10.05	0.097	150552.	0.00966	0.00015	0.00018	0.00998
11.78	0.114	176527.	0.00820	0.00020	0.00015	0.00855
13.52	0.131	202493.	0.00687	0.00026	0.00012	0.00725
15.25	0.147	228448.	0.00566	0.00033	0.00009	0.00608
17.41	0.168	260778.	0.00431	0.00043	0.00007	0.00480
18.71	0.181	280336.	0.00358	0.00050	0.00005	0.00413
20.45	0.198	306265.	0.00272	0.00059	0.00004	0.00335
22.18	0.214	332188.	0.00198	0.00069	0.00003	0.00270
23.91	0.231	358100.	0.00136	0.00080	0.00002	0.00217
25.63	0.248	384005.	0.00085	0.00092	0.00001	0.00178

ELEMENT LOSSES
ELEMENT #10: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.60	0.082	2849458.	0.00000	0.16000	0.00000	0.16000
11.25	0.107	2829062.	0.00000	0.11973	0.00000	0.11973
13.17	0.126	2808982.	0.00000	0.10007	0.00000	0.10007
15.04	0.143	2789259.	0.00000	0.08583	0.00000	0.08583
17.32	0.165	2765162.	0.00000	0.07261	0.00000	0.07261
18.69	0.178	2750826.	0.00000	0.06625	0.00000	0.06625
20.49	0.195	2732093.	0.00000	0.05920	0.00000	0.05920
22.28	0.212	2713664.	0.00000	0.05334	0.00000	0.05334
24.07	0.229	2695530.	0.00000	0.04840	0.00000	0.04840
25.85	0.246	2677681.	0.00000	0.04418	0.00000	0.04418

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 9: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF.			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT # 9:LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	0.01246	0.10241
11.78	0.114	0.018877	0.01248	0.08734
13.52	0.131	0.021653	0.01250	0.07614
15.25	0.147	0.024429	0.01251	0.06749
17.41	0.168	0.027886	0.01252	0.05912
18.71	0.181	0.029978	0.01252	0.05500
20.45	0.198	0.032750	0.01252	0.05034
22.18	0.214	0.035522	0.01251	0.04641
23.91	0.231	0.038293	0.01249	0.04306
25.63	0.248	0.041063	0.01248	0.04015

ELEMENT LOSSES
ELEMENT #11: VANED DIFFUSER

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.47	0.082	235193.	0.09116	0.00077	0.09976	0.19169
11.07	0.107	307604.	0.07636	0.00130	0.09352	0.17117
12.97	0.126	360233.	0.06606	0.00177	0.08904	0.15687
14.80	0.143	411199.	0.05678	0.00229	0.08478	0.14385
17.05	0.165	473602.	0.04637	0.00302	0.07968	0.12906
18.40	0.178	510999.	0.04064	0.00350	0.07668	0.12082
20.17	0.195	560298.	0.03367	0.00420	0.07279	0.11066
21.94	0.212	609342.	0.02739	0.00495	0.06902	0.10137
23.69	0.229	658178.	0.02180	0.00577	0.06534	0.09291
25.45	0.246	706850.	0.01686	0.00665	0.06177	0.08527

ELEMENT LOSSES
ELEMENT #12: TURNING CHANNEL

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.47	0.082	552191.	0.00000	0.00029	0.00000	0.00029
11.07	0.107	722198.	0.00000	0.00050	0.00000	0.00050
12.97	0.126	845762.	0.00000	0.00069	0.00000	0.00069
14.80	0.143	965422.	0.00000	0.00089	0.00000	0.00089
17.05	0.165	1111932.	0.00000	0.00119	0.00000	0.00119
18.39	0.178	1199734.	0.00000	0.00138	0.00000	0.00138
20.17	0.195	1315479.	0.00000	0.00166	0.00000	0.00166
21.93	0.212	1430625.	0.00000	0.00196	0.00000	0.00196
23.69	0.229	1545284.	0.00000	0.00229	0.00000	0.00229
25.44	0.246	1659556.	0.00000	0.00264	0.00000	0.00264

ELEMENT LOSSES
ELEMENT #13: DOWNCOMER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
8.48	0.082	149343.	0.00000	0.00000	0.00000	0.00000
11.09	0.107	195322.	0.00000	0.00000	0.00000	0.00000
12.99	0.126	228741.	0.00000	0.00000	0.00000	0.00000
14.83	0.143	261104.	0.00000	0.00000	0.00000	0.00000
17.08	0.165	300728.	0.00000	0.00001	0.00000	0.00001
18.43	0.178	324474.	0.00000	0.00001	0.00000	0.00001
20.20	0.195	355778.	0.00000	0.00001	0.00000	0.00001
21.97	0.212	386920.	0.00000	0.00001	0.00000	0.00001
23.73	0.229	417930.	0.00000	0.00001	0.00000	0.00001
25.49	0.246	448836.	0.00000	0.00001	0.00000	0.00001

ELEMENT LOSSES
ELEMENT #15: IMPELLER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
10.05	0.097	150552.	0.00966	0.00015	0.00018	0.00998
11.78	0.114	176527.	0.00820	0.00020	0.00015	0.00855
13.52	0.131	202493.	0.00687	0.00026	0.00012	0.00725
15.25	0.147	228448.	0.00566	0.00033	0.00009	0.00608
17.41	0.168	260778.	0.00431	0.00043	0.00007	0.00480
18.71	0.181	280336.	0.00358	0.00050	0.00005	0.00413
20.45	0.198	306265.	0.00272	0.00059	0.00004	0.00335
22.18	0.214	332188.	0.00198	0.00069	0.00003	0.00270
23.91	0.231	358100.	0.00136	0.00080	0.00002	0.00217
25.63	0.248	384006.	0.00085	0.00092	0.00001	0.00178

BOUNDARY/OPERATING CONDITIONS
ELEMENT #14: LEAKAGE w/ RS RWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
REAR WEAR RING LEAKAGE COEF.			0.015		
REAR WEAR RING CLEARANCE [in]			0.001		
REAR WEAR RING DIAMETER [in]			0.400		
% REAR WEAR RING STATIC HEAD LOST			0.150		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #14: LEAKAGE w/ RS RWR

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	-0.00272	0.10286
11.78	0.114	0.018877	0.00578	0.08772
13.52	0.131	0.021653	0.00739	0.07647
15.25	0.147	0.024429	0.00842	0.06778
17.41	0.168	0.027886	0.00931	0.05938
18.71	0.181	0.029978	0.00973	0.05524
20.45	0.198	0.032750	0.01018	0.05056
22.18	0.214	0.035522	0.01053	0.04662
23.91	0.231	0.038293	0.01082	0.04324
25.63	0.248	0.041063	0.01105	0.04033

BOUNDARY/OPERATING CONDITIONS
ELEMENT #16: LEAKAGE w/ FS FWR

IMP. INLET TIP DIAMETER [in]			0.643		
IMP. INLET HUB DIAMETER [in]			0.399		
IMP. DISC. TIP DIAMETER [in]			1.873		
IMP. DISC. HUB DIAMETER [in]			1.873		
FRONT WEAR RING LEAKAGE COEF.			0.007		
FRONT WEAR RING CLEARANCE [in]			0.001		
FRONT WEAR RING DIAMETER [in]			0.400		
STATIC HEAD RISE [ft]	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00

LEAKAGE OUTPUT
ELEMENT #16: LEAKAGE w/ FS FWR

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	LEAKAGE FLOW RATE [lb/s]	LEAKAGE POWER LOSS COEF
10.05	0.097	0.016099	0.01246	0.10241
11.78	0.114	0.018877	0.01248	0.08734
13.52	0.131	0.021653	0.01250	0.07614
15.25	0.147	0.024429	0.01251	0.06749
17.41	0.168	0.027886	0.01252	0.05912
18.71	0.181	0.029978	0.01252	0.05500
20.45	0.198	0.032750	0.01252	0.05034
22.18	0.214	0.035522	0.01251	0.04641
23.91	0.231	0.038293	0.01249	0.04306
25.63	0.248	0.041063	0.01248	0.04015

ELEMENT LOSSES
ELEMENT #17: VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
9.43	0.090	2870251.	0.00000	0.14615	0.00000	0.14615
11.29	0.107	2849635.	0.00000	0.11942	0.00000	0.11942
13.15	0.125	2829402.	0.00000	0.10033	0.00000	0.10033
15.02	0.143	2809534.	0.00000	0.08605	0.00000	0.08605
17.34	0.165	2785268.	0.00000	0.07261	0.00000	0.07261
18.74	0.178	2770836.	0.00000	0.06613	0.00000	0.06613
20.61	0.196	2751980.	0.00000	0.05893	0.00000	0.05893
22.47	0.214	2733435.	0.00000	0.05296	0.00000	0.05296
24.33	0.232	2715193.	0.00000	0.04793	0.00000	0.04793
26.19	0.249	2697242.	0.00000	0.04365	0.00000	0.04365

ELEMENT LOSSES
ELEMENT #18: 1-DISC. VOLUTE

IMPELLER SPEED[RPM] 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
9.30	0.090	1104590.	0.18889	0.00185	0.01212	0.20286
11.13	0.107	1322900.	0.18432	0.00265	0.00934	0.19631
12.97	0.125	1541204.	0.17985	0.00359	0.00700	0.19044
14.81	0.143	1759488.	0.17548	0.00467	0.00506	0.18522
17.10	0.165	2031476.	0.17018	0.00621	0.00317	0.17957
18.48	0.178	2196068.	0.16704	0.00726	0.00229	0.17659
20.32	0.196	2414337.	0.16296	0.00877	0.00138	0.17311
22.16	0.214	2632613.	0.15896	0.01042	0.00075	0.17014
23.99	0.232	2850871.	0.15505	0.01222	0.00034	0.16762
25.83	0.249	3069136.	0.15123	0.01416	0.00012	0.16550

ELEMENT LOSSES
ELEMENT #19: 1-DISC. EXIT DIFF.

IMPELLER SPEED[RPM] = 74000

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
9.28	0.090	762084.	0.00000	0.00000	0.00249	0.00249
11.12	0.107	912701.	0.00000	0.00000	0.00357	0.00357
12.96	0.125	1063314.	0.00000	0.00000	0.00484	0.00484
14.79	0.143	1213914.	0.00000	0.00000	0.00631	0.00631
17.08	0.165	1401565.	0.00000	0.00000	0.00841	0.00841
18.46	0.178	1515122.	0.00000	0.00000	0.00982	0.00982
20.29	0.196	1665710.	0.00000	0.00000	0.01187	0.01187
22.13	0.214	1816305.	0.00000	0.00000	0.01412	0.01412
23.96	0.232	1966886.	0.00000	0.00000	0.01656	0.01656
25.80	0.249	2117473.	0.00000	0.00000	0.01919	0.01919

Advanced Engine Test Bed (AETB) Turbopump

The AETB is a volute type turbopump developed at Pratt and Whitney. This pump was developed for throttling capabilities for future space missions like the Mark 49-F Turbopump. The CPAC pump model configuration considers only 1 stage of the AETB. The actual pump consists of 2 such stages on a single shaft.

CPAC aetb various speeds

PUMP MODEL CONFIGURATION

ELEMENT NUMBER	ELEMENT TYPE	INLET TO NODE	DISC. TO NODE
1	INDUCER	1	2
2	IMPELLER	2	3
3	VANLESS DIFFUSER	3	4
4	1-DISC. VOLUTE	4	5

FLUID PROPERTIES

FLUID DENSITY [lb/ft^3]	4.391
FLUID VISCOSITY [ft^2/s]	0.00000200

OVERALL PUMP PERFORMANCE

IMPELLER SPEED [RPM] = 99985

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
183.89	1.80	0.0285	0.3878	1.0189	0.3806	47521.5	1409.8	38.7
294.18	2.88	0.0456	0.4963	0.8910	0.5570	60151.5	1733.6	38.7
404.57	3.96	0.0628	0.5361	0.8512	0.6298	64754.2	1784.4	38.7
514.96	5.04	0.0799	0.5461	0.8262	0.6609	65875.9	1700.6	38.7
624.95	6.11	0.0969	0.5379	0.8023	0.6705	64874.1	1524.4	38.7
764.94	7.48	0.1187	0.5089	0.7727	0.6587	61405.8	1192.5	38.7
845.93	8.28	0.1312	0.4846	0.7559	0.6411	59867.8	994.0	38.7
955.93	9.35	0.1483	0.4444	0.7334	0.6060	59164.1	742.3	38.7
1066.92	10.44	0.1655	0.3968	0.7112	0.5580	58267.3	454.0	38.7
1199.91	11.74	0.1861	0.3311	0.6850	0.4833	57022.2	65.8	38.7

GEOMETRY
ELEMENT #1: INDUCER

INLET TIP DIAMETER [in]	2.43
INLET HUB DIAMETER [in]	1.35
INLET PASSAGE WIDTH [in]	0.54
INLET BLADE ANGLE [deg]	9.2
NUMBER OF INLET BLADES	3
INLET NORMAL THICKNESS [in]	0.024
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	2.43
DISCH. HUB DIAMETER [in]	1.63
DISCH. PASSAGE WIDTH [in]	0.4
DISCH. BLADE ANGLE [deg]	12.3
NUMBER OF DISCH. BLADES	3
DISCH. NORMAL THICKNESS [in]	0.05
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	5.24
SURFACE ROUGHNESS [in]	0.036

GEOMETRY
ELEMENT #2: IMPELLER

INLET TIP DIAMETER [in]	2.43
INLET HUB DIAMETER [in]	1.63
INLET PASSAGE WIDTH [in]	0.4
INLET BLADE ANGLE [deg]	12.3
NUMBER OF INLET BLADES	6
INLET NORMAL THICKNESS [in]	0.024
INLET BLOCKAGE	0.95
DISCH. TIP DIAMETER [in]	4.437
DISCH. HUB DIAMETER [in]	4.437
DISCH. PASSAGE WIDTH [in]	0.1
DISCH. BLADE ANGLE [deg]	40
NUMBER OF DISCH. BLADES	24
DISCH. NORMAL THICKNESS [in]	0.05
DISCH. BLOCKAGE	0.9
BLADE LENGTH [in]	0.65
SURFACE ROUGHNESS [in]	0.036

BOUNDARY/OPERATING CONDITIONS
ELEMENT # 2: IMPELLER

MAX. EFFICIENCY HEAD COEF:				0.570	
MAX. EFF. IMPELLER DISCHARGE FLOW COEF:				0.070	
IMPELLER CLEARANCE TORQUE COEF:				0.010	
IMPELLER BLADE LOADING COEF (AA)				-6328.570	
IMPELLER BLADE LOADING COEF (BB)				3143.020	
IMPELLER BLADE LOADING COEF (CC) :				-370.000	
IMPELLER FRONT SHROUD CLEARANCE [in]:				0.0310	
IMPELLER REAR SHROUD CLEARANCE [in]:				0.0500	
INLET PRESSURE [PSIA]				0.00	
INLET BYPASS FLOW RATE [%]:				0.00	
INLET CU [ft/s]·	196.03	174.39	152.74	131.09	109.51
	82.05	66.17	44.59	22.82	-3.26
INLET TEMP. [R]	38.67	38.67	38.67	38.67	38.67
	38.67	38.67	38.67	38.67	38.67

GEOMETRY
ELEMENT #3: VANLESS DIFFUSER

INLET TIP DIAMETER [in]	4.437
INLET HUB DIAMETER [in]	4.437
INLET PASSAGE WIDTH [in]	0.1
INLET BLOCKAGE	0.9
DISCH. TIP DIAMETER [in]	4.7
DISCH. HUB DIAMETER [in]	4.7
DISCH. PASSAGE WIDTH [in]	0.15
DISCH. BLOCKAGE	0.9
SURFACE ROUGHNESS [in]	0.0036

GEOMETRY
ELEMENT #4: 1-DISC. VOLUTE

THROAT DIAMETER [in]	0.524
THROAT AREA [in^2]	0.2157
BLOCKAGE	0.95
SURFACE ROUGHNESS	0.0086

FLUID VELOCITIES
INDUCER INLET
(ELEMENT # 1 NODE # 1)
IMPELLER SPEED[RPM] = 99985
URMS[ft/s] 858.22

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
183.89	1.799	0.01087	21.05	0.00	21.05	131.67
294.18	2.878	0.01738	33.68	0.00	33.68	210.65
404.57	3.959	0.02391	46.32	0.00	46.32	289.70
514.96	5.039	0.03043	58.96	0.00	58.96	368.74
624.95	6.115	0.03693	71.55	0.00	71.55	447.51
764.94	7.485	0.04521	87.57	0.00	87.57	547.75
845.93	8.277	0.04999	96.85	0.00	96.85	605.74
955.93	9.353	0.05649	109.44	0.00	109.44	684.51
1066.92	10.439	0.06305	122.15	0.00	122.15	763.98
1199.91	11.741	0.07091	137.37	0.00	137.37	859.21

FLUID VELOCITIES
INDUCER DISCHARGE
(ELEMENT # 1 NODE # 2)
IMPELLER SPEED[RPM] = 99985
URMS[ft/s] 903.37

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
183.89	1.799	0.01512	29.29	762.98	763.55	137.51
294.18	2.878	0.02419	46.86	678.78	680.40	219.99
404.57	3.959	0.03327	64.45	594.50	597.99	302.54
514.96	5.039	0.04235	82.04	510.23	516.78	385.10
624.95	6.115	0.05139	99.56	426.25	437.73	467.35
764.94	7.485	0.06290	121.86	319.38	341.84	572.03
845.93	8.277	0.06956	134.76	257.54	290.67	632.60
955.93	9.353	0.07861	152.29	173.57	230.91	714.86
1066.92	10.439	0.08774	169.97	88.83	191.78	797.86
1199.91	11.741	0.09867	191.15	-12.70	-191.58	897.31

FLOW ANGLES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	DISCHARGE(NODE # 2) BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
183.89	1.799	1.41	90.00	7.79	11.79	2.20	0.51
294.18	2.878	2.25	90.00	6.95	11.79	3.95	0.51
404.57	3.959	3.09	90.00	6.11	11.79	6.19	0.51
514.96	5.039	3.93	90.00	5.27	11.79	9.13	0.51
624.95	6.115	4.77	90.00	4.43	11.79	13.15	0.51
764.94	7.485	5.83	90.00	3.37	11.79	20.88	0.51
845.93	8.277	6.44	90.00	2.76	11.79	27.62	0.51
955.93	9.353	7.27	90.00	1.93	11.79	41.26	0.51
1066.92	10.439	8.10	90.00	1.10	11.79	62.41	0.51
1199.91	11.741	9.09	90.00	0.11	11.79	-86.20	0.51

FLUID VELOCITIES
IMPELLER INLET
(ELEMENT # 2 NODE # 2)
IMPELLER SPEED[RPM] 99985
URMS[ft/s] = 903.37

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
183.89	1.799	0.01415	27.41	762.99	763.48	128.65
294.18	2.878	0.02263	43.84	678.79	680.20	205.81
404.57	3.959	0.03112	60.30	594.51	597.56	283.04
514.96	5.039	0.03962	76.75	510.23	515.97	360.27
624.95	6.115	0.04808	93.14	426.25	436.31	437.22
764.94	7.485	0.05885	114.00	319.38	339.12	535.15
845.93	8.277	0.06508	126.07	257.54	286.75	591.82
955.93	9.353	0.07354	142.47	173.57	224.55	668.77
1066.92	10.439	0.08208	159.01	88.83	182.14	746.42
1199.91	11.741	0.09231	178.83	-12.70	-179.28	839.46

FLUID VELOCITIES
IMPELLER DISCHARGE
(ELEMENT # 2 NODE # 3)
IMPELLER SPEED[RPM] 99985
URMS[ft/s] = 1937.26

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]	RELATIVE W (RMS) [ft/s]
183.89	1.799	0.02852	55.26	1748.60	1749.48	85.96
294.18	2.878	0.04563	88.40	1697.71	1700.01	137.52
404.57	3.959	0.06275	121.57	1648.52	1653.01	189.13
514.96	5.039	0.07988	154.74	1600.79	1608.26	240.74
624.95	6.115	0.09694	187.79	1554.45	1565.76	292.16
764.94	7.485	0.11865	229.86	1497.00	1514.55	357.60
845.93	8.277	0.13121	254.20	1464.44	1486.34	395.46
955.93	9.353	0.14828	287.25	1420.95	1449.70	446.88
1066.92	10.439	0.16549	320.60	1377.84	1414.65	498.77
1199.91	11.741	0.18612	360.56	1327.11	1375.23	560.94

FLOW ANGLES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] = 99985

		INLET(NODE # 2)			DISCHARGE(NODE # 3)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
183.89	1.799	11.05	2.06	1.25	16.32	1.81	23.68
294.18	2.878	11.05	3.70	1.25	20.25	2.98	19.75
404.57	3.959	11.05	5.79	1.25	22.83	4.22	17.17
514.96	5.039	11.05	8.55	1.25	24.70	5.52	15.30
624.95	6.115	11.05	12.33	1.25	26.13	6.89	13.87
764.94	7.485	11.05	19.64	1.25	27.57	8.73	12.43
845.93	8.277	11.05	26.08	1.25	28.26	9.85	11.74
955.93	9.353	11.05	39.38	1.25	29.09	11.43	10.91
1066.92	10.439	11.05	60.81	1.25	29.82	13.10	10.18
1199.91	11.741	11.05	-85.94	1.25	30.58	15.20	9.42

FLUID VELOCITIES
VANLESS DIFFUSER INLET
(ELEMENT # 3 NODE # 3)
IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
183.89	1.799	0.02428	47.03	1748.60	1749.24
294.18	2.878	0.03884	75.24	1697.71	1699.38
404.57	3.959	0.05342	103.48	1648.52	1651.78
514.96	5.039	0.06799	131.72	1600.79	1606.21
624.95	6.115	0.08251	159.85	1554.45	1562.66
764.94	7.485	0.10100	195.65	1497.00	1509.73
845.93	8.277	0.11169	216.37	1464.44	1480.34
955.93	9.353	0.12621	244.50	1420.95	1441.84
1066.92	10.439	0.14087	272.89	1377.84	1404.61
1199.91	11.741	0.15842	306.91	1327.11	1362.14

FLUID VELOCITIES
VANLESS DIFFUSER DISCHARGE
(ELEMENT # 3 NODE # 4)
IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	FLOW COEF	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
183.89	1.799	0.01528	29.60	1650.75	1651.02
294.18	2.878	0.02444	47.36	1602.71	1603.41
404.57	3.959	0.03362	65.13	1556.28	1557.65
514.96	5.039	0.04279	82.90	1511.21	1513.49
624.95	6.115	0.05193	100.60	1467.47	1470.92
764.94	7.485	0.06356	123.14	1413.23	1418.59
845.93	8.277	0.07029	136.18	1382.49	1389.19
955.93	9.353	0.07943	153.88	1341.44	1350.24
1066.92	10.439	0.08866	171.75	1300.74	1312.04
1199.91	11.741	0.09971	193.16	1252.85	1267.66

FLOW ANGLES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] = 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 3) BETA FLUID [deg]	INLET(NODE # 3) ALPHA (RMS) [deg]	INLET(NODE # 3) DEVIATION ANGLE [deg]	DISCHARGE(NODE # 4) BETA FLUID [deg]	DISCHARGE(NODE # 4) ALPHA (RMS) [deg]	DISCHARGE(NODE # 4) DEVIATION ANGLE [deg]
183.89	1.799	1.54	1.54	-1.54	1.03	1.03	-1.03
294.18	2.878	2.54	2.54	-2.54	1.69	1.69	-1.69
404.57	3.959	3.59	3.59	-3.59	2.40	2.40	-2.40
514.96	5.039	4.70	4.70	-4.70	3.14	3.14	-3.14
624.95	6.115	5.87	5.87	-5.87	3.92	3.92	-3.92
764.94	7.485	7.45	7.45	-7.45	4.98	4.98	-4.98
845.93	8.277	8.40	8.40	-8.40	5.63	5.63	-5.63
955.93	9.353	9.76	9.76	-9.76	6.54	6.54	-6.54
1066.92	10.439	11.20	11.20	-11.20	7.52	7.52	-7.52
1199.91	11.741	13.02	13.02	-13.02	8.76	8.76	-8.76

FLUID VELOCITIES
1-DISC. VOLUTE INLET
(ELEMENT # 4 NODE # 4)
IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
183.89	1.799	29.60	1650.75	1651.02
294.18	2.878	47.36	1602.71	1603.41
404.57	3.959	65.13	1556.28	1557.65
514.96	5.039	82.90	1511.21	1513.49
624.95	6.115	100.60	1467.47	1470.92
764.94	7.485	123.14	1413.23	1418.59
845.93	8.277	136.18	1382.49	1389.19
955.93	9.353	153.88	1341.44	1350.24
1066.92	10.439	171.75	1300.74	1312.04
1199.91	11.741	193.16	1252.85	1267.66

FLUID VELOCITIES
1-DISC. VOLUTE DISCHARGE
(ELEMENT # 4 NODE # 5)
IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	MERIDION CM (RMS) [ft/s]	TANGENTIAL CU(RMS) [ft/s]	ABSOLUTE C(RMS) [ft/s]
183.89	1.799	287.95	0.00	287.95
294.18	2.878	460.66	0.00	460.66
404.57	3.959	633.52	0.00	633.52
514.96	5.039	806.39	0.00	806.39
624.95	6.115	978.62	0.00	978.62
764.94	7.485	1197.84	0.00	1197.84
845.93	8.277	1324.67	0.00	1324.67
955.93	9.353	1496.90	0.00	1496.90
1066.92	10.439	1670.71	0.00	1670.71
1199.91	11.741	1878.96	0.00	1878.96

FLOW ANGLES
ELEMENT # 4:1-DISC. VOLUTE

IMPELLER SPEED[RPM] 99985

		INLET(NODE # 4)			DISCHARGE(NODE # 5)		
VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]	BETA FLUID [deg]	ALPHA (RMS) [deg]	DEVIATION ANGLE [deg]
183.89	1.799	1.03	1.03	-1.54	90.00	90.00	-1.03
294.18	2.878	1.69	1.69	-2.54	90.00	90.00	-1.69
404.57	3.959	2.40	2.40	-3.59	90.00	90.00	-2.40
514.96	5.039	3.14	3.14	-4.70	90.00	90.00	-3.14
624.95	6.115	3.92	3.92	-5.87	90.00	90.00	-3.92
764.94	7.485	4.98	4.98	-7.45	90.00	90.00	-4.98
845.93	8.277	5.63	5.63	-8.40	90.00	90.00	-5.63
955.93	9.353	6.54	6.54	-9.76	90.00	90.00	-6.54
1066.92	10.439	7.52	7.52	-11.20	90.00	90.00	-7.52
1199.91	11.741	8.76	8.76	-13.02	90.00	90.00	-8.76

NODAL PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	INLET(NODE # 1) TOTAL HEAD [ft]	TEMP. [R]	NPSH AVAIL. [ft]	VAPOR PRES [PSIA]	STATIC PRES [PSIA]	DISCHARGE(NODE # 2) TOTAL HEAD [ft]	TEMP. [R]	STATIC PRES [PSIA]
183.89	1.799	2295.6	38.7	-1825.3	20.687	69.8	18596.8	38.7	290.8
294.18	2.878	2295.6	38.7	-990.2	20.687	69.5	16533.9	38.7	284.8
404.57	3.959	2295.6	38.7	-249.0	20.687	69.0	14051.6	38.7	259.0
514.96	5.039	2295.6	38.7	397.6	20.687	68.4	11151.7	38.7	213.5
624.95	6.115	2295.6	38.7	947.8	20.687	67.6	7847.0	38.7	148.5
764.94	7.485	2295.6	38.7	1512.2	20.687	66.4	3041.8	38.7	37.4
845.93	8.277	2295.6	38.7	1769.2	20.687	65.6	1313.0	38.7	0.0
955.93	9.353	2295.6	38.7	2036.7	20.687	64.3	828.6	38.7	0.0
1066.92	10.439	2295.6	38.7	2211.4	20.687	62.9	571.6	38.7	0.0
1199.91	11.741	2295.6	38.7	2294.8	20.687	61.1	570.4	38.7	0.0

ELEMENT LOSSES
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
183.89	1.799	2071044.	0.03533	0.00364	0.00493	0.04391
294.18	2.878	3313220.	0.02817	0.00933	0.00383	0.04132
404.57	3.959	4556524.	0.02181	0.01764	0.00286	0.04232
514.96	5.039	5799826.	0.01627	0.02859	0.00204	0.04689
624.95	6.115	7038624.	0.01155	0.04210	0.00136	0.05501
764.94	7.485	8615275.	0.00672	0.06307	0.00069	0.07048
845.93	8.277	9527480.	0.00451	0.07714	0.00041	0.08206
955.93	9.353	10766277.	0.00222	0.09850	0.00014	0.10086
1066.92	10.439	12016337.	0.00072	0.12270	0.00001	0.12344
1199.91	11.741	13514156.	0.00001	0.15520	0.00000	0.15521

ELEMENT PERFORMANCE
ELEMENT # 1:INDUCER

IMPELLER SPEED[RPM] = 99985

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	REYNOLDS NUMBER	HEAD COEF	POWER COEF	EFF	HEAD RISE [ft]	PRES RISE [PSID]	TEMP RISE [R]
183.89	1.80	2071044.	0.1397	0.1837	0.7609	16301.2	221.0	0.0
294.18	2.88	3313220.	0.1221	0.1634	0.7471	14238.3	215.3	0.0
404.57	3.96	4556524.	0.1008	0.1431	0.7043	11756.0	190.0	0.0
514.96	5.04	5799826.	0.0759	0.1228	0.6182	8856.1	145.1	0.0
624.95	6.11	7038624.	0.0476	0.1026	0.4638	5551.4	80.9	0.0
764.94	7.48	8615275.	0.0064	0.0769	0.0832	746.2	-29.0	0.0
845.93	8.28	9527480.	-0.0084	0.0620	-0.3237	-982.6	-65.6	0.0
955.93	9.35	10766277.	-0.0126	0.0418	-1.4141	-1467.0	-64.3	0.0
1066.92	10.44	12016337.	-0.0148	0.0214	-4.7727	-1724.0	-62.9	0.0
1199.91	11.74	13514156.	-0.0148	-0.0031	51.7775	-1725.3	-61.1	0.0

ELEMENT LOSSES
ELEMENT # 2:IMPELLER

IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
183.89	1.799	881680.	0.00000	0.00088	0.00034	0.00122
294.18	2.878	1410497.	0.00000	0.00226	0.00002	0.00227
404.57	3.959	1939793.	0.00000	0.00427	0.00000	0.00427
514.96	5.039	2469089.	0.00000	0.00691	0.00000	0.00691
624.95	6.115	2996466.	0.00000	0.01018	0.00000	0.01018
764.94	7.485	3667675.	0.00000	0.01525	0.00001	0.01525
845.93	8.277	4056017	0.00000	0.01865	0.00001	0.01866
955.93	9.353	4583395.	0.00000	0.02381	0.00001	0.02383
1066.92	10.439	5115568.	0.00000	0.02966	0.00002	0.02968
1199.91	11.741	5753216.	0.00000	0.03752	0.00003	0.03755

ELEMENT LOSSES
ELEMENT # 3:VANLESS DIFFUSER

IMPELLER SPEED[RPM] 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
183.89	1.799	21251634.	0.00000	0.25432	0.00000	0.25432
294.18	2.878	20642460.	0.00000	0.14572	0.00000	0.14572
404.57	3.959	20058886.	0.00000	0.09725	0.00000	0.09725
514.96	5.039	19498118.	0.00000	0.07020	0.00000	0.07020
624.95	6.115	18959852.	0.00000	0.05321	0.00000	0.05321
764.94	7.485	18302014.	0.00000	0.03914	0.00000	0.03914
845.93	8.277	17934596.	0.00000	0.03333	0.00000	0.03333
955.93	9.353	17450520.	0.00000	0.02720	0.00000	0.02720
1066.92	10.439	16979044.	0.00000	0.02247	0.00000	0.02247
1199.91	11.741	16436277.	0.00000	0.01816	0.00000	0.01816

ELEMENT LOSSES
ELEMENT # 4:1-DISC. VOLUTE

IMPELLER SPEED[RPM] = 99985

VOLUME FLOW RATE [GPM]	MASS FLOW RATE [lb/s]	REYNOLDS NUMBER	INCIDENCE LOSS COEF	SKIN FRIC LOSS COEF	DIFFUSION LOSS COEF	TOTAL LOSS COEF
183.89	1.799	6287626.	0.17493	0.00158	0.03881	0.21532
294.18	2.878	10058834.	0.16099	0.00405	0.02567	0.19071
404.57	3.959	13833462.	0.14799	0.00765	0.01542	0.17106
514.96	5.039	17608088.	0.13583	0.01240	0.00803	0.15625
624.95	6.115	21369040.	0.12448	0.01826	0.00331	0.14605
764.94	7.485	26155708.	0.11106	0.02736	0.00051	0.13893
845.93	8.277	28925130.	0.10379	0.03346	0.00005	0.13730
955.93	9.353	32686084.	0.09444	0.04273	0.00000	0.13716
1066.92	10.439	36481228.	0.08559	0.05322	0.00000	0.13882
1199.91	11.741	41028556.	0.07574	0.06732	0.00000	0.14306

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 99985

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
183.89	1.80	0.0285	0.3878	1.0189	0.3806	47521.5	1409.8	38.7
294.18	2.88	0.0456	0.4963	0.8910	0.5570	60151.5	1733.6	38.7
404.57	3.96	0.0628	0.5361	0.8512	0.6298	64754.2	1784.4	38.7
514.96	5.04	0.0799	0.5461	0.8262	0.6609	65875.9	1700.6	38.7
624.95	6.11	0.0969	0.5379	0.8023	0.6705	64874.1	1524.4	38.7
764.94	7.48	0.1187	0.5089	0.7727	0.6587	61405.8	1192.5	38.7
845.93	8.28	0.1312	0.4846	0.7559	0.6411	59867.8	994.0	38.7
955.93	9.35	0.1483	0.4444	0.7334	0.6060	59164.1	742.3	38.7
1066.92	10.44	0.1655	0.3968	0.7112	0.5580	58267.3	454.0	38.7
1199.91	11.74	0.1861	0.3311	0.6850	0.4833	57022.2	65.8	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 94191

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
173.23	1.69	0.0285	0.3878	1.0189	0.3806	44266.3	1314.9	38.7
277.13	2.71	0.0456	0.4963	0.8910	0.5570	55242.8	1595.3	38.7
381.12	3.73	0.0628	0.5361	0.8512	0.6298	59048.2	1631.8	38.7
485.12	4.75	0.0799	0.5461	0.8262	0.6609	59717.3	1547.5	38.7
588.74	5.76	0.0969	0.5379	0.8023	0.6705	58456.3	1379.7	38.7
720.61	7.05	0.1187	0.5089	0.7727	0.6587	54837.5	1068.8	38.7
796.91	7.80	0.1312	0.4846	0.7559	0.6411	53278.1	886.7	38.7
900.53	8.81	0.1483	0.4444	0.7334	0.6060	52599.1	661.6	38.7
1005.09	9.83	0.1655	0.3968	0.7112	0.5580	51774.2	404.9	38.7
1130.37	11.06	0.1861	0.3311	0.6850	0.4833	50669.2	60.3	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 85629

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
157.48	1.54	0.0285	0.3878	1.0189	0.3806	37977.2	1129.2	38.7
251.94	2.47	0.0456	0.4963	0.8910	0.5570	46923.0	1357.1	38.7
346.48	3.39	0.0628	0.5361	0.8512	0.6298	49916.5	1382.6	38.7
441.02	4.32	0.0799	0.5461	0.8262	0.6609	50292.7	1307.6	38.7
535.22	5.24	0.0969	0.5379	0.8023	0.6705	49048.9	1162.8	38.7
655.11	6.41	0.1187	0.5089	0.7727	0.6587	45765.0	896.8	38.7
724.47	7.09	0.1312	0.4846	0.7559	0.6411	44112.4	735.2	38.7
818.67	8.01	0.1483	0.4444	0.7334	0.6060	43521.7	548.3	38.7
913.73	8.94	0.1655	0.3968	0.7112	0.5580	42824.3	335.7	38.7
1027.62	10.05	0.1861	0.3311	0.6850	0.4833	41910.9	50.9	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 77066

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
141.73	1.39	0.0285	0.3878	1.0189	0.3806	31435.8	935.2	38.7
226.74	2.22	0.0456	0.4963	0.8910	0.5570	38651.7	1118.9	38.7
311.83	3.05	0.0628	0.5361	0.8512	0.6298	41040.2	1138.5	38.7
396.92	3.88	0.0799	0.5461	0.8262	0.6609	41302.5	1076.4	38.7
481.70	4.71	0.0969	0.5379	0.8023	0.6705	40246.8	957.6	38.7
589.60	5.77	0.1187	0.5089	0.7727	0.6587	37516.6	740.1	38.7
652.03	6.38	0.1312	0.4846	0.7559	0.6411	35750.2	596.1	38.7
736.80	7.21	0.1483	0.4444	0.7334	0.6060	35264.6	444.5	38.7
822.35	8.05	0.1655	0.3968	0.7112	0.5580	34695.9	272.2	38.7
924.86	9.05	0.1861	0.3311	0.6850	0.4833	33956.1	41.5	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 68503

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
125.99	1.23	0.0285	0.3878	1.0189	0.3806	25557.5	760.9	38.7
201.55	1.97	0.0456	0.4963	0.8910	0.5570	31228.9	905.1	38.7
277.18	2.71	0.0628	0.5361	0.8512	0.6298	33079.9	919.4	38.7
352.82	3.45	0.0799	0.5461	0.8262	0.6609	33244.9	869.1	38.7
428.17	4.19	0.0969	0.5379	0.8023	0.6705	32362.6	773.8	38.7
524.09	5.13	0.1187	0.5089	0.7727	0.6587	30135.4	599.8	38.7
579.58	5.67	0.1312	0.4846	0.7559	0.6411	28391.2	475.4	38.7
654.94	6.41	0.1483	0.4444	0.7334	0.6060	27875.4	351.6	38.7
730.98	7.15	0.1655	0.3968	0.7112	0.5580	27422.3	215.3	38.7
822.10	8.04	0.1861	0.3311	0.6850	0.4833	26837.8	33.0	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] = 59940

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
110.24	1.08	0.0285	0.3878	1.0189	0.3806	20342.7	606.2	38.7
176.36	1.73	0.0456	0.4963	0.8910	0.5570	24654.8	715.7	38.7
242.53	2.37	0.0628	0.5361	0.8512	0.6298	26035.9	725.6	38.7
308.71	3.02	0.0799	0.5461	0.8262	0.6609	26120.0	685.7	38.7
374.65	3.67	0.0969	0.5379	0.8023	0.6705	25396.3	611.3	38.7
458.57	4.49	0.1187	0.5089	0.7727	0.6587	23621.2	475.9	38.7
507.13	4.96	0.1312	0.4846	0.7559	0.6411	22240.9	379.4	38.7
573.07	5.61	0.1483	0.4444	0.7334	0.6060	21354.1	269.5	38.7
639.61	6.26	0.1655	0.3968	0.7112	0.5580	21003.4	165.1	38.7
719.33	7.04	0.1861	0.3311	0.6850	0.4833	20555.9	25.5	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 51377

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
94.49	0.92	0.0285	0.3878	1.0189	0.3806	15791.3	471.2	38.7
151.16	1.48	0.0456	0.4963	0.8910	0.5570	18929.4	550.7	38.7
207.89	2.03	0.0628	0.5361	0.8512	0.6298	19908.0	556.8	38.7
264.61	2.59	0.0799	0.5461	0.8262	0.6609	19927.7	526.3	38.7
321.13	3.14	0.0969	0.5379	0.8023	0.6705	19348.1	470.2	38.7
393.06	3.85	0.1187	0.5089	0.7727	0.6587	17974.1	368.6	38.7
434.68	4.25	0.1312	0.4846	0.7559	0.6411	16915.2	296.2	38.7
491.20	4.81	0.1483	0.4444	0.7334	0.6060	15700.6	198.4	38.7
548.23	5.36	0.1655	0.3968	0.7112	0.5580	15439.3	121.5	38.7
616.57	6.03	0.1861	0.3311	0.6850	0.4833	15110.5	19.0	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 42814

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
78.74	0.77	0.0285	0.3878	1.0189	0.3806	11903.4	355.8	38.7
125.97	1.23	0.0456	0.4963	0.8910	0.5570	14052.7	410.1	38.7
173.24	1.70	0.0628	0.5361	0.8512	0.6298	14696.4	413.3	38.7
220.51	2.16	0.0799	0.5461	0.8262	0.6609	14668.1	390.8	38.7
267.61	2.62	0.0969	0.5379	0.8023	0.6705	14217.8	350.3	38.7
327.55	3.20	0.1187	0.5089	0.7727	0.6587	13194.2	277.7	38.7
362.23	3.54	0.1312	0.4846	0.7559	0.6411	12414.2	226.1	38.7
409.33	4.01	0.1483	0.4444	0.7334	0.6060	11172.3	146.0	38.7
456.86	4.47	0.1655	0.3968	0.7112	0.5580	10729.9	84.7	38.7
513.81	5.03	0.1861	0.3311	0.6850	0.4833	10501.5	13.5	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED[RPM] 34251

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
62.99	0.62	0.0285	0.3878	1.0189	0.3806	8678.8	260.0	38.7
100.77	0.99	0.0456	0.4963	0.8910	0.5570	10024.8	293.9	38.7
138.59	1.36	0.0628	0.5361	0.8512	0.6298	10401.0	294.8	38.7
176.41	1.73	0.0799	0.5461	0.8262	0.6609	10341.2	279.2	38.7
214.08	2.09	0.0969	0.5379	0.8023	0.6705	10005.5	251.8	38.7
262.04	2.56	0.1187	0.5089	0.7727	0.6587	9281.3	203.2	38.7
289.78	2.84	0.1312	0.4846	0.7559	0.6411	8737.8	168.9	38.7
327.46	3.20	0.1483	0.4444	0.7334	0.6060	7877.5	115.6	38.7
365.48	3.58	0.1655	0.3968	0.7112	0.5580	6883.3	54.7	38.7
411.04	4.02	0.1861	0.3311	0.6850	0.4833	6729.1	8.9	38.7

OVERALL PUMP PERFORMANCE

IMPELLER SPEED [RPM] 25688

VOLUME FLOWRATE [GPM]	MASS FLOWRATE [lb/s]	FLOW COEF	HEAD COEF	POWER COEF	EFF	TOTAL HEAD [ft]	TOTAL PRES [PSIA]	TEMP [R]
47.24	0.46	0.0285	0.3878	1.0189	0.3806	6117.8	184.0	38.7
75.58	0.74	0.0456	0.4963	0.8910	0.5570	6845.5	202.1	38.7
103.94	1.02	0.0628	0.5361	0.8512	0.6298	7021.9	201.6	38.7
132.30	1.29	0.0799	0.5461	0.8262	0.6609	6947.0	191.5	38.7
160.56	1.57	0.0969	0.5379	0.8023	0.6705	6711.2	174.7	38.7
196.53	1.92	0.1187	0.5089	0.7727	0.6587	6235.6	145.3	38.7
217.34	2.13	0.1312	0.4846	0.7559	0.6411	5886.0	124.6	38.7
245.59	2.40	0.1483	0.4444	0.7334	0.6060	5337.4	92.7	38.7
274.11	2.68	0.1655	0.3968	0.7112	0.5580	4707.0	56.2	38.7
308.28	3.02	0.1861	0.3311	0.6850	0.4833	3855.5	7.1	38.7